Transport Modelling: Towards Operational Standards in Europe

MOTOS Handbook containing guidelines for constructing national and regional transport models

Handbook of transport modelling (in Europe): learning from best practice
PART 1: General Handbook and Model Descriptions
& PART 2: Policy Issues and Models
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Handbook of transport modelling (in Europe): learning from best practice

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Part 1: General Handbook and Model Descriptions

1 Introduction

1.1 Why this handbook?

Transport modelling in the new Member States is a difficult job, for model developers are faced with poor data availability and a lack of adequate tools and instruments. As a consequence, policy makers can be concerned about the appropriateness of the impact assessment of socioeconomic and environmental indicators. Moreover, there is a lack of consistency in common transport modelling between bordering countries, i.e. at European regional level.

Therefore, it is of crucial importance for developing common European transport models, to identify the immediate user needs and main bottlenecks on transport modelling in the new Member States. The new Member States have a particular interest to set up, enhance and/or link transport models at national and/or regional levels based on their needs. This handbook tries to support transport modellers and policy makers by basing the transport models for the new Member States on common best practice principles. This approach will bring advantages both in terms of costs and of performance. Efficiency and effectiveness will be achieved by applying proven methodologies for design, development, data use, practical use and maintenance of the models. Besides, best practices will give an example for linking models (bordering territories) and data aggregation (checking or feeding national models with data from regional models, or European models from national models).

This handbook provides guidance and an incentive for new Member States to progressively move towards its application, as they find it appropriate. This should in turn facilitate the linking of bordering models and/or aggregation of models, thereby paving the way for a bottom-up path to establishing better-grounded transport models at the more aggregate (national or EU) level.

The high-level goal of this handbook is to support transport policy in Europe by defining common good practice principles for national and regional transport modelling. These principles are to satisfy the immediate needs of model developers in the new Member States, and contribute to establishing a standardized approach for transport modelling in the European Union.

1.2 Process of producing this handbook

This handbook is the result of the European project MOTOS (Transport Modelling: Towards Operational Standards in Europe). The full-size version of the handbook is available in hard
copy format and on the MOTOS website: http://www.projectmotos.eu. The process to come to this product was:

1. first to describe the user needs in the new member states and current state of affairs within the field of transport modelling. The MOTOS project has put considerable effort into determining the user needs of model developers and policy-makers. The user needs analysis was supported by targeted workshops (four) in the new Member States and questionnaires;
2. an extensive description was made of the state-of-the-art of transport modelling and a number of best practice examples were collected and described and
3. finally all the information was put together in one handbook, resulting in a document of more than 400 pages. Added to this document are all kind of hyperlinks to make it for the user much easier to find the information he is looking for.

1.3 Structure of the report

The structure of this handbook is as follows. Chapter 2 (Part 1) provides a general description of the modelling process. Topics discussed include data collection, model estimation, uncertainties in models, linkage to other models and transport modelling software.

Part 2 (Chapter 3) of the handbook addresses modelling issues from the point of view of users, i.e. the policy-makers. The aim of is to describe for each issue the process followed by policy-makers who have identified a “problem” and need a model to resolve it. These issues are then linked to modelling processes (passenger demand modelling, freight demand modelling, assignment models, economic models and/or impact models). A list of present models that can be used as a reference case is also presented, as well as a link to best practice examples.

Part 3 is the report on state-of-the-art transport modelling, best practice examples, and linking of models.

Part 4 is the report on common best practice principles in European transport modelling. The report is divided into 6 groups of best practice examples: freight, passenger demand, economic modelling, assignment, mode specific models, and integration of models.

Within MOTOS, the choice was made to update the MDir (retrieved from the 4th Framework Spotlights TN Project), which gives an overview of models used in Europe including the contact details of the modellers. The MDir has been posted on the project website. Appendix A (Modelling Directory) gives a overview of the collected information.

1.4 Use of the Handbook

This handbook can be used in two ways. Firstly, the hard copy of this handbook can be used for normal reading. For more information about a specific transport modelling subject, references to literature (in the list of references at the end of this handbook) and references to
the report on state-of-the-art and best practice examples are given in parts 3 and 4, respectively.

Secondly, the digital version of this handbook provides ‘hyperlinks’. These can be found in part 2 of the handbook and can be used to directly read on about a specific topic of interest in part 3 (state-of-the-art) or part 4 (best practice examples). By clicking on the hyperlink the reader is directed to the section in question.

So, if you want to know more about any of the subjects listed below now, just click on the corresponding subject:
- Strategic mobility;
- Demand analysis;
- Land use planning;
- Industrial location decisions;
- Ex-ante policy analysis;
- Investment analysis;
- Modal shift;
- Infrastructure planning;
- Pricing;
- Road traffic management;
- Urban public transport planning;
- Rail transport planning;
- Intermodal solutions;
- Project impact assessment;
- Environment and safety;
- Capacity utilization.
2 General definition of modelling

This first part of the handbook addresses transport modelling in terms of general modelling principles. We started from the idea that models are constructed to resolve a specific policy problem or issue. Next, the steps were determined that are required to actually construct a transport model.

In the second part of the handbook, we worked from the perspective of a specified policy issue, looking at the models available to shed light on that policy issue. This allows the reader of the handbook to start from both approaches.

This chapter comprises the first part of the handbook and contains the following paragraphs:
2.1 Introduction to the process of modelling
2.2 Methodological overview
2.3 Data collection, data requirements and scenarios
2.4 Estimation, calibration and validation
2.5 Uncertainties in models
2.6 Linkage to other models
2.7 Stakeholders and institutional environment
2.8 Intellectual property rights
2.9 Software

2.1 Introduction to the process of modelling

The process of developing a transport model is complicated and difficult to describe as there are a wide variety of transport problems, different needs on the part of policy-makers, different situations in terms of availability of information and data. These circumstances make it difficult to describe a “one size fits all” modelling process that can be used as general basis of transport model construction. Below is a brief description of the construction of the Dutch freight transport model.

In 1989, the Dutch Ministry of Transport, Waterways and Public Works ordered an evaluation study of the Dutch freight models by the University of Antwerp. This evaluation study concluded that a strategic model was needed which was policy sensitive and could assist public decision makers with some upcoming complex decisions in the area of freight transport. In the period 1990-1993 a number of ideas studies was drafted by various consultants for the development of this strategic model. In 1993 the SMILE model development was initiated. A 2 year contract of about 600 kEuro was awarded to a consortium of TNO, NEI and QQQ for the specification and implementation of the model, based on one of the ideas studies. The model was delivered in 1998 to the Ministry. After that the model was used for different policy studies in the Netherlands. In 2003 an update of the model was undertaken.
In order to describe the modelling process, a distinction can be made between six general phases with sub-classifications:

1. Policy needs
   1.1. Determine policy needs through policy process
   1.2. Stakeholder analysis and consultation
   1.3. Consulting process/round table,
   1.4. Independent reporters (dependent on size)
2. Organisation
   2.1. Budget, planning, ambitions
   2.2. Project organisation
   2.3. Scope and type of model
   2.4. Choice of software/GIS
   2.5. Establish maintenance procedure
   2.6. Tendering
3. Develop a model
   3.1. Data issues
   3.2. Methodological foundation
   3.3. Develop a blueprint
   3.4. Confirm/reconsider choice of software
   3.5. Estimation and calibration
   3.6. Implementation and testing
   3.7. Validation
   3.8. Use of the model
4. Auditing, updating and validating by non-project experts
5. Produce available, accessible, well-documented and understandable documents
6. Public acceptance

The six phases of transport model development are explained in greater detail below.

2.1.1 Policy needs, which issues to address
The starting point for developing a model is reflected in the figure below, which shows the different phases of the policy process. These consist of the exploration of future developments, identification of policy options for policy development, assessment of benefits and drawbacks of policy options, monitoring the implementation of policy measures, and evaluating the outcomes of policy measures before the next steps can be taken in terms of policy development. In general, when policy-makers are confronted with a problem, they will formulate a policy objective (e.g. a reduction in the number of fatalities in traffic accidents). In order to develop a policy, information and tools to support the development of a policy are needed.
The aim of MOTOS is to provide a transport modelling handbook for the new Member States, the main focus being placed on the user needs identified in these States in the course of the MOTOS project (see deliverable 1). It is also worth mentioning that some of the user needs in the EU15 may also arise in the new Member States in the next few years. Therefore, the needs identified in the old Member States may become important to the new Member States and form a guideline for developing transport models. An overview of the policy issues/objectives and their relationship with the models that provide outcomes to evaluate policy can be found in “FP6-2002-SSP-1/502002 TRANSFORUM Scientific forum on transport forecast validation and policy assessmentD3.2 Report Forum 2: the fitness for purpose of definitions and indicators”\(^{1}\). Once the need for a model is determined from a policy perspective, the following steps can be taken as part of the first phase of model construction:

- **stakeholder analysis and consultation.** In order to develop a policy, the intervention of stakeholders may be necessary. For example, the construction of new infrastructure involves different stakeholders, such as the users of the new infrastructure, but also any stakeholders who will be affected by the external effects of the new infrastructure (noise, emissions, etc.). It is essential that an initial analysis is made of those who benefit from and those who are adversely affected by the policy.

- **consulting process/round table.** By having stakeholders explicitly included in the first stages of the modelling process, the policy may become more effective because of two reasons. Firstly, all effects from the implementation of a policy can be inventoried. Secondly, the modelling process will become visible for the different stakeholders and hence become more credible. This will help in gaining public acceptance of the model.

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\(^{1}\) http://www.transforum-eu.net
independent reporters. Depending on the size of the study, independent reporters may be
generated to assess the necessity to model the policy intervention and the way in which the
model should be implemented. It is common practice in the Netherlands (see textbox
above) and for the UK Department of Transport and SIKA in Sweden to call in
independent experts to help develop national models.

2.1.2 Organisation
The second phase concerns the organisation of constructing a transport model, with a focus on
laying the foundation for the modelling phase and consecutive steps. This is mainly a task for
the institution that commissions the study. The following organisational issues are important
when developing a transport model:

- **Budget, planning, ambitions.** The budget is one of the determining factors in developing a
  transport model. The budget will depend on the urgency of the problem, i.e. a model
developed for a bridge construction, such as the Fehrmanbelt between Denmark and
Germany, will be highly urgent. A model of this kind will absorb only a fraction of the
building cost of the bridge and is an essential element for construction (it provides input
for the dimensions of the infrastructure; i.e. dual lane, 4-lane). More generally, policy
models developed for a country or region will be less urgent. A model for strategic
mobility can range from a very simple forecasting method on aggregate figures to a very
detailed regional model covering all modes of transport and covering both passenger
transport and freight. A very detailed regional model covering passenger and freight will
cost a government about 1 to 2 million euros, whereas a simple regional model covering
road traffic only can be constructed at a mere cost of 100,000 euros. Of course, building a
detailed model requires a substantial amount of planning. For multimodal models, this
may take a country a few years. The planning of a model depends on the time schedule of
the policy-maker. Usually, after some time an answer will be needed, such as in the case
of the bridge construction. In this phase, one should consider the data available to
estimate, calibrate and validate the transport model. This may absorb a considerable part
of the budget earmarked for the model.

- **Project organisation.** The Ministry of Transport and regional directorate of the Ministry
of Transport are the ones usually involved in organising the project. They form the group
that monitors the construction of the model, and the (intermediate) results are presented to
them. In addition, representatives from public transport companies (bus and railway
companies), and stakeholders from the freight sector (shipper organisations, transport
organisations) are often included in the group.

- **Scope and type of model.** These are determined by the policy issues at hand; if there are
recurring questions about detailed issues involving traffic on networks, then a detailed
network will have to be developed. If one wants to address the capacity issues on the
network, a model covering both freight and passenger demand should be developed. Also,
the type of model is defined by the policy issue. If one wants to address a change in the
share of transport modes ensuing from a specific policy, the model should include a modal
split that is able to capture the changes that occur due to the implementation of the policy.
For example, higher fuel taxes for road transport should be reflected in the model in the shape of higher vehicle user cost.

- **Choice of software/GIS.** These days, all transport models are supported by a geographical information system (GIS). This allows the results of the model to be made better visible, also for policy-makers. Moreover, the choice of software is an important issue. Customers may already have other software in place on which other parts of the model are run. This may influence the choice of software to be used for the model.

- **Establish maintenance procedure.** Provided that it is calibrated and validated, a model can nowadays be used for about 2 to 5 years, after which an update will be needed. This means that new data will be needed for model input, calibration and validation. This aspect has to be thought of in the first stages of the development of a model. In some cases, a model will be constructed for just the one study, i.e. the construction of the Great Belt bridge, but even here, the model is updated for ex-ante policy.

- **Tendering.** The last issue is about who will construct the model. It is very common practice to put the development of a strategic model out to tender. This means that one first has to describe the Terms of Reference covering the previous points (budget (including budget of civil servants), project organisation, scope and type of model, choice of software and maintenance). Usually 3 to 5 leading companies are invited to submit a tender on the basis of the Terms of Reference. If the Ministry has a specialist in-house department that can perform the modelling, it may choose not to put the study out to tender, and instead to develop the model in house. This used to be common practice in the past, but is hardly done nowadays. Practically all modelling studies are put out to tender.

2.1.3 Development of the model

Once the contract has been awarded, the model construction phase can start. Within the modelling process the following steps are identified:

- **Data issues.** The availability of data is an important issue. If no data is available, then it should be collected. In budgetary terms and terms of efforts, data collection and preparation may take about 50% of the modelling budget. One possible way of reducing costs in this phase is to use as much data as is available from the national bureaus of statistics and international organisations (Eurostat, UN-ECE). Alternatively, data can be taken from previous studies. In some cases, for instance disaggregate studies, survey data will have to be used that is collected through interviews with respondents. This is, in general, a costly way of collecting data. The issue of data collection will be elaborated on in section 2.3 of this handbook.

- **Methodological foundation.** Firstly, the choice should be made of whether to use a disaggregate or aggregate modelling approach. The model should be founded either on individual data (individual travellers/factories) or on macro data (groups of travellers or factories). In addition, there are other differences and similarities between existing transport models, which can be summarised according to a number of dimensions:
- Top-down or bottom-up? Most national passenger demand models represent the behaviour of individuals and households based on disaggregate data with aggregation taking place in the assignment phase in order to reflect link flows and congestion. The British NRTF model starts from projections of aggregate traffic growth, which is imposed on a statistical representation of road capacity in order to estimate speed changes and behavioural adjustments. Both the bottom-up approach in the Netherlands (NMS) and the British top-down approach have been successfully applied over a long period of time, and have both gradually been improved to accommodate changing policy demands.

- Trip, tour or activity-based? Almost all available national passenger demand models are trip-based or tour-based. The only activity-based example is the Danish PETRA model, which handles chains consisting of single tours or dual-tour combinations, each with one or two destinations. Depending on the chain choice, predications are made of destination and modal choice. The number of possible chains is limited to 13.

- Modelling changes or levels? The Dutch NMS model is used to predict changes in travel patterns, which are applied to base-year travel matrices. Accordingly, this “pivoting” approach requires complete and reliable base matrices. The alternative and most common approach is to predict levels of travel after proper calibration of the models.

- New model or an updated/re-estimated version? As mentioned above, both the Dutch NMS model and the British NRTF model have been subject to gradual improvements and the NMS model has recently been updated and re-estimated. In Sweden, the decision was taken to develop a new model system (SAMPERS) to replace less integrated existing regional and national models. The advantage of gradual development is continuity, although a complete overhaul and integration are easier achieved if a fresh start is made.

- National/regional model system or single model? Some national models (e.g. NMS and NRTF) have been developed alongside, and have been inspired by and complement, existing regional models. In other cases (notably SAMPERS), the new system is designed to deliver comprehensive and integrated results on regional, national, and international travel.

- Handling of international linkages? Some models cover cross-border transport of freight (Italian DSS) or passengers (Italian DSS, Swedish SAMPERS), while most models are strictly confined to a national context.

- Standard assignment software? Both the Dutch NMS and the Italian DSS use assignment techniques that do not rely on major commercial software packages. This contributes to flexibility in terms of use and development, but at the same time requires more resources to develop the model and acquire the skills to use it. The open availability of SAMPERS to potential users may be hampered by the licensing terms of the assignment method used (EMME/2).
User friendliness? The aim of the Italian DSS is to serve as a decision support system, and one of the main objectives of SAMPERS was to achieve a user-friendly modelling environment. However, the complexity of modern modelling systems for freight and passenger traffic tends to restrict their application to a very small group of experts. There is a trade-off between modelling of highly segmented and complex demand structures in detailed geographical settings, on the one hand, and data requirements, running times and difficulties in interpreting results, on the other hand.

- **Develop a blueprint.** It is useful, especially when a group of independent modelling teams are available, to develop a blueprint which sets the mechanisms or numerical relationships of the model and fixes the data input and modelling outcome.

- **Confirm/reconsider choice of software.** Given the previous step, the choice of software for the model may be reconsidered.

- **Estimation and calibration.** The modelling mechanisms/numerical relationships have to be estimated, which results in estimations of the model parameters. This phase in the model development process usually requires a considerable amount of time and effort. One important element is accuracy of calibration. Sometimes, rules of thumb are applied. 90% of cases should be within a 10% deviation, 95% within 20%, although this varies from case to case and should be considered very carefully.

- **Implementation and testing.** After all modal relationships have been quantified, the model can be put together and test runs can be made.

- **Validation.** Once the model is put together and implemented, validation takes place. One method of validation is backcasting. Performance of the model is tested by comparing the outcome to the real-life situation based on a previous year for which input and output data are available.

- **Use of the model.** Once the model is ready for use, a proper user manual should be available to allow users other than the members of the development team to run the model. In the event of a large model, different teams usually work on different parts of the model at the same time, so the user manual becomes a vital document that describes the model as a whole. In the model exploitation phase, a logbook recording the experiences in running the model may also be helpful. As far as general policy models are concerned, a series of standard scenarios and results are sometimes listed for policy-makers to use as a kind of reference card when asked about the effects. For example, in the Netherlands, a booklet with standard scenarios is available, including for example, scenarios with 2% GDP growth and 3% growth. If policy-maker are asked about the effects of 2.5% growth, they can quickly refer to the results listed in the booklet.
2.1.4 Auditing, updating, and validating by non-project experts
It is very important that transport models should be peer reviewed by experts. The review results will be used to update the model. Finally, a validation methodology should be developed to check the inputs from different scenarios and the results of the various runs during the use of the model. This works as a “logbook” for the model and is worthwhile for the model owner to track the performance of the model. Also, by keeping track of the results, one can compare the outcome of the model with the real-life situation. It also provides input for validation purposes.

2.1.5 Production of available, accessible, well-documented and understandable documents
Communication between the developers of a transport model and those who wish to use the outcome of the model as a starting point for policy discussions is essential. It will makes both parties aware of each other’s concerns, thoughts, etc., about the transport model. For example, documentation and manuals describing the ins and outs of the model is necessary to better understand how model behaviour is simulated. Documentation is also necessary to work hands-on with the model, change/add modules, etc., because it often happens that policymakers claim that modellers do not understand them and vice versa. Providing accessible information prevents policymakers from misunderstanding the capabilities of a model. In an earlier stage of the modelling process, modellers should be make an effort to understand the policymakers’ wishes.

2.1.6 Public acceptance
As modelling results play an increasingly important role in the debate about the feasibility of new infrastructure projects, it will be helpful to ensure that the model and its outcome are understood by a wider audience than just the modellers and stakeholders. In the course of time, some models will become “institutionalised” and will not be put under scrutiny every time a new model run is made. This can be achieved by presenting the outcomes to a large audience and to have the results included in the policy papers issued by policy-makers.

2.2 Methodological overview
This methodological overview provides a brief description of how to apply various types of transport models. Details are given on the most common modelling approaches, aspects, and terminology of the following modelling principles:

- Freight demand modelling
- Passenger demand modelling
- Economic modelling
- Assignment modelling

These are explained in greater detail in chapters 6, 7, 8 and 9 of part 3, which also provide many examples and information to the reader for further reference.
2.2.1 Methodological overview of freight demand modelling

In order to develop or monitor policies, indicators are needed to measure the effects. For questions related to the past and current situation, data can be directly used to determine the indicator. However, for future situations no data is available, and models are needed to predict the indicators. These models rely on existing data on the basis of which they are calibrated.

Freight transport generally involves longer distances than passenger transport. For this reason, the international aspects are very important even when studying regional or local transport issues. Some examples of this issue are given in the introduction to chapter 6 of part 3.

Policy issues

The demand for freight demand modelling is generated by different policy issues. For instance, pricing has become an issue in Europe and models are needed to study the situational response to cost changes. Moreover, in a 24-hour economy like ours, businesses engage in production and logistics operations day and night. Models are needed to provide an insight into the sprawl of flows over different periods of the day. Many other examples are given in subsection 6.1.1 of part 3.

Conceptual framework for freight modelling

The freight transport system can be divided into five layers that together form a conceptual framework for freight transport modelling. The first layer deals with decisions about the location of production and consumption, type of product, and volume. The second layer establishes a trade relationship, describing sales between production and consumption locations. In the third layer, decisions are made on the use and location of inventories and supply chain management. Subsequently, in the fourth layer, transport modes and vehicles are chosen that are used to carry the goods. Finally, the last layer determines the transport route across the network. Subsection 6.1.2 of part 3 provides an overview of modelling developments within the layers of the framework.

Modelling methods for freight

For freight transport, it has been common practice to skip the logistics step (layer 3) or combine it with trade modelling (layer 2). There are also other approaches in which several layers are combined into a single step, resulting in one, two, three or four-step models. In the following paragraphs, a brief description is given of several modelling techniques that are applied in the different framework layers. A further elaboration is given in the above-mentioned subsection.

Different methods are applied to estimate production and consumption. A simple approach is the application of a growth model with the help of which base-year statistics on freight trips leaving or entering a zone are scaled up on the basis of regional changes in variables such as employment, population, or GDP. Another method involves applying input-output models, which are built from input-output tables that describe in monetary units the contributions made by each sector of the economy to other sections of the economy. Final demand by consumers, and imports and exports are also included.
In the trade layer, relationships are determined between production zones and consumption zones. The gravity model is a well-known model to determine from where to where goods are traded. Flows are distributed between the model zones, using the product of the production and consumption measures between origin and destination, divided by a measure of generalized transport costs. The higher the generalised transport costs between regions, the lower the volume of the goods traded between these regions.

One of the most obvious manifestations of logistics activities is the growth in freight transport measured in tonne-kilometre. The length of haulage journeys has been the main driver of the increased demand for goods transport, rather than the increase in the number of tonnes lifted. This is strongly influenced by changing logistics structures. Emerging stakeholders in the transport sector (freight integrators) search for efficient transport combinations that significantly reduce costs, and they provide carriers with tailor-made solutions.

Modal-split models estimate the distribution over different transport services and can be divided into aggregate modal-split models, disaggregate modal-split models, and multi-modal network models.

- **Aggregate modal-split models** predict the shares of different modes for a number of zones. They can be based on the economic theory of individual utility maximisation under restrictive assumptions.

- **In disaggregate models**, modal choice is modelled at the level of individual shipments. They can be based on the economic theory of individual utility maximisation under general assumptions. The models are calibrated on the basis of data of, for instance, surveys of carriers and commodity surveys.

- **Multi-modal network models** predict mode and route choice simultaneously, by determining the optimal mode-route path through the network with cost minimisation algorithms. The solution may involve one or more changes in modes, hence this approach can model intermodal movements directly.

To determine the routing through the network, assignment models are used. One type of assignment model is the above-mentioned multi-modal network assignment. Another type of assignment model is based on discrete choice and shortest route algorithms. If congestion is an issue, it is important to assign passenger transport and freight transport simultaneously to the network.

2.2.2 Methodological overview passenger demand modelling

**Passenger demand modelling** represents one perspective of the metropolitan or regional transport system. The supply side represents the other perspective in terms of infrastructure and flow-dependent costs and travel times. The whole transport system is part of a region in which people live, work, and engage in leisure activities. The development of land use patterns and location of activities strongly determine travel demands in terms of trip generation and attraction, and rely on transport systems that provide accessibility.
The interacting floor space and transport markets are affected by policies in terms of decision-making. Policies that operate in the long-term through structural planning will mainly affect the supply side. Policies prompted by more short-term incentives will affect urban actors in terms of their behaviour in both the short- and long-term. The interaction between transport and location can be measured by indicators that inform the decision-making system whether political goals such as sustainable development or other measures are attained.

The analysis of transport demand and supply is mostly done for urban and regional transport planning by so-called four-step models. The following four steps are addressed: trip generation, trip distribution, modal split, and trip assignment. Details of these steps are given in subsection 7.1.3 of part 3.

This subsection provides an overview of approaches to passenger demand modelling and their connection to transport supply modelling. Moreover, mutual dependencies between the transport system and spatial environment (e.g. the economy, land use, and ecological systems) are discussed, and two modelling approaches outlined, i.e. trip-based models and activity-based models. Since the focus is on the metropolitan and regional level, the state-of-the-art and major trends in land use and transport modelling are described. Additional information can be found in section 7.1 of part 3.

**State-of-practice in passenger demand modelling**

Transport demand analysis should be placed in a wider context, because transport demand in a region depends on factors such as land use and the regional development of the economy. The analysis of passenger demand needs to be integrated with trip assignment to achieve consistency between demand projections and level-of-service projections. In other words, once demands on the assigned links are known, accurate estimations can be made of travel time, travel costs, and travel comfort. The need for integrated analysis is underpinned by the fact that policies affecting infrastructure supply and operation interact with transport demand. Two main modelling traditions can be distinguished, more specifically trip-based and activity-based modelling. They are briefly addressed in this handbook, but in section 7.2 of part 3 a more elaborate description and additional examples are given.

In general, there are three generations of travel demand models, namely trip-based, tour-based and activity-based demand models. The figure below shows that the trip-based model handles the four trips independently (2 home-based work trips HBW and 2 other home-based trips HBO). A tour-based model models 2 tours instead of 4 independent trips. In that way, the model takes advantages of zonal properties like home zone generation and destination zone attraction. The activity-based model models the trips in the context of activities.
Trip-based and tour-based modelling
The predominant type of model in current passenger demand modelling is the so-called nested multinomial logit model category applied to return trips (home-based). The total choice set is divided into groups (nests), with the probability of an alternative choice being the outcome of the probability of choosing the relevant nest and the probability of choosing the relevant alternative within the nest. An example of a nested model structure is given in Figure 2-2.

Activity-based modelling
Modelling travel demand from an activity-participation point of view is based on the time-geography theory which says that the activities of individuals are limited by a number of personal and social constraints. These constraints can be distinguished into capability constraints (need for eating and sleeping), coupling constraints (having a family dinner requires all members to be present at same location at same time), and authority constraints (shop opening hours). Because of these constraints, individuals can only be at different locations at different points in time by experiencing the time and cost of travelling. Therefore, it is assumed that travelling to destinations by certain travel modes at certain times of day result from the demand for activity participation.

In discrete choice activity-based models, combinations of activity purposes are modelled explicitly in what is called activity pattern models. Activity patterns can be defined as a sequence of activities planned by an individual. Discrete choice activity-based models rely on the random utility theory, and have the following advantages.

- Large sets of activity patterns can be handled
- Long-term effects can be incorporated into discrete choice models
- Attributes of transport system performance are included in the model structure

In rule-based simulation models activities are generated for each member of a household. The activities are sequentially ordered and combined into chains, while taking into account the temporal, spatial, and institutional constraints. Key theoretical advantages of rule-based simulation models are given below.

- The demand for travel derives from the demand for activity participation in a manner that is close to actual decision-making
- Time, location and budget constraints are explicitly incorporated into the model structure
The time component is modelled continuously

Many simulation models are household-based

A wider spectrum of transport policy measures has developed because of growing traffic congestion and environmental problems in urban regions. These issues are increasingly difficult to meet by capacity expansion, and therefore transport demand management has included measures such as congestion charging, traffic information, and traffic control.

**Land use/transport models** represent a partial view of the world from a spatial-economic-transport point of view, in terms of categories of economic actors and the interaction between them. Actors like investors, developers, producers, residents, and transport suppliers create markets by interacting such as financial markets, labour markets, transport markets, product markets, and property markets. State-of-the-art examples, trends, and normative approaches to this type of modelling are discussed in sections 7.4 of the State-of-the-Art report.

### 2.2.3 Methodological overview of economic modelling

Economic models are used to identify the consequences of transport policies that are not covered by transport models. Since transport demand can be derived from economic activities, they are also used to calculate changes in transport demand that are used as input for transport models.

Economic models can be used to emphasize benefits or costs arising in addition to the direct transport effects. Some of these effects may be very important to illustrate from a political perspective. Three typical economic modelling approaches can be distinguished.

- Economic models linked to passenger transport
- Economic models linked to freight transport
- Economic models with no connection to specific transport models

The main purpose of economic models that are linked to transport models is to predict demand (as input for the transport model) based on economic activities. The introduction to chapter 8 of part 3 provides a description of different applications of these three types of economic models.

As previously mentioned, economic models often serve as a generator of transport or traffic demand. In addition, they are used to address very specific economic issues. Models that reflect the real-life situation, with identifiable regions, sectors, and types of households, are those most commonly used. They are models based on, for example, the national economy, regional economies, trade, or household decisions.

Economic models are often linked to other models, either as a direct integrated part of a transport model or a separate model linked to a systems approach. Economic models play an important role in relation to the generation of traffic. Freight transport demand is prompted by the need to move goods between sellers and buyers in different geographical locations. In most transport models (systems), the trade in goods is calculated using a specific economic
model or economic sub-module. The various possibilities for applying these models are described in greater detail below.

Passenger traffic demand, such as commuting, is also prompted by economic activities. However, many personal trips are not directly linked to any economic activity. Leisure trips are not directly motivated by purely economic benefit, but rather by personal utility, which is an economic activity. Because of that, economic models have not played as crucial a role in relation to passenger models. The economic variables included in most passenger transport models are GDP growth, location patterns, and prices. These variables may be taken from economic models (e.g. macro-economic national models), but often there is no specific economic model included.

This handbook does not extensively address the various types of economic models. However, in subsection 8.1.1 of part 3, they are discussed in greater detail, and table 8.3 of part 3 provides an overview of their main characteristics.

**Input-output models** represent flows of money and goods between the various producers and consumers in the economy. The models are based on the assumption that companies produce goods in fixed proportions between the input factor (labour and capital) and between other intermediate inputs. This means that, even if some inputs become relatively more expensive compared to others, companies will use the same mix of input as they do in the base situation. This is a restrictive assumption, as companies as a rule will change the collection of input if relative prices change. Placed in this context, it is a matter of production substitution effects.

Input-output models are based on input-output tables. They specify the amount of output from a given industry that is used for production by other industries and for final consumption by private households or the government. Similarly, input-output tables show how the inputs to one industry are composed of outputs from other industries.

**Computable general equilibrium models** are typical comparative static equilibrium models of interregional trade based in micro-economics, using utility and production functions with substitution between inputs. CGE models are comprehensive and cover relationships between sectors, supply and demand, households, and economic regulations in potentially very complex non-linear ways. The models can thus be used to analyse multi-issue problems.

**Dynamic macro-economic models** are dynamic non-spatial macro-economic models. Some are designed around error-correction models estimated from long national time series, and include dynamic adjustment mechanisms. The dynamic aspect is important in explaining time series.

**Cost minimization models** are designed to find the best possible solution according to clearly defined alternatives by minimising system costs for various different policy aims. The system describes flows of goods and equipment, and energy consumption. There are several problems in relation to these models. For one, they are normative rather than descriptive models, which is not in line with modern-day modelling needs. Furthermore, there is no integration with other economic activities and the demand aspect is exogenous.
In **system dynamics models**, relations and exchanges between economic sectors, agents and production factors are modelled using difference equations. These equations describe changes over time for a given entity in a given sector as a function of variables from other sectors. The level of detail with respect to sectors, zones and factors is very low and simplified due to the complexity of the model. SDMs do not, therefore, pursue quantitative precision, but instead provide a qualitative description of the evolution of and responses in an economic system.

**Time series models** are developed on the basis of historical trends that are extrapolated into the future. For these models, a large number of econometric methods exist, but in terms of transport models, much simpler methods are often applied. Time series models may in some cases not even be monetary, because the variables can be physical variables, such as weights and volumes. Generally, many observations are required to estimate the models and they often provide better predictions of future changes than those provided by models that are estimated on the basis of cross section data.

**Zone-rate models** estimate transport demand on the basis of simple indicators. Zone-based data, such as the number of businesses, workplaces, homes and households, are used to establish statistical relationships for production and household demand. These models are generally applied when data is sparse or weak or when model development resources pose a constraint.

To conclude, production and demand calculations must be based on spatial input-output models. Economic growth projections can be based on macro-economic dynamic models. Subsection 8.1.2 of part 3 explains in greater detail the challenges faced and possible ways of addressing them.

### 2.2.4 Methodological overview of assignment modelling

Assignment models assign transport data as trip matrices to the transport network. Transport demand follows routes in the network. As the routes are not known beforehand, the model needs a route choice generation principle. Some assignment models describe congestion in the network. In this case, the model has to re-calculate and assign transport in order to find an equilibrium between demand (route choice) and supply in the transport network. Assignment models have other functions as well, such as estimation of travel resistance between zones, and modelling route choice in models for estimation of trip matrices.

If there is a fixed demand for travel in a given network, the assignment model will have three stages with a cyclic structure. The first is supply as reflected by links and speed-flow relations, the second is route choice, and the third is the assignment algorithm.

**Supply**

The supply-side of assignment models describes the transport network. Traditionally, this has been built as mathematical graphs, consisting of links and nodes, while public transport models usually include more complex network descriptions. Subsection 9.1.1 of part 3 explains in greater detail how supply for roads and public transport is determined.
Route choice
The basic premise in most assignment procedures is the assumption of a rational traveller, one who selects a route that generates the least perceived individual costs. There are many factors that influence choice of route when travelling between two points. Examples include journey time, distance, financial costs (fuel and other), congestion, type of manoeuvres required, type of road, scenery, signposting, road works, reliability of travel times, and habit. Because it is difficult to include all these elements in an assignment model, using approximations is inevitable. The issues discussed in the following paragraphs are looked at in greater detail in subsection 9.1.2 of part 3.

Most route choice models are based on some concept of generalised costs. Journey times and journey costs can be expressed generally. Individuals will usually choose the lowest cost option.

The aim of route choice modelling is to generate routes with mutually independent characteristics in the choice set. However, it is difficult to create unbiased choice sets, because alternatives are easily correlated since different alternatives often share common links. This requires paying special attention to choice set generation and correlation of alternatives.

In some situations, differences between user preferences will have to be considered. Accordingly, random coefficient models are used to identify individual preferences within a population.

When the route choice mechanism and input are specified, an algorithm will be needed to assign traffic to the network. The basic ingredient of assignment models is a shortest path algorithm that searches for feasible paths between two zones, and subsequently selects the shortest one. Using a shortest path algorithm, the simplest assignment algorithm assigns all traffic to the shortest path, known as the all-or-nothing assignment. However, when traffic on a given road segment increases, speeds drop and queues arise. One of the main differences between assignment models is whether or not they take account of these capacity restraints. Another is whether the model considers the fact that road users may use a different route for unknown reasons (stochastic).

Subsection 9.1.4 of part 3 discusses the following assignment models:

- All-or-nothing models
- Capacity dependent models
- System optimal solutions
- Stochastic models
- Stochastic models with capacity

General assignment models have many extensions, some of which are briefly discussed below and explained in greater detail in subsection 9.1.5 of part 3.
Some general assignment models only describe the assignment of one class. The split into multi-class models may be important if different units use the same road space, as when lorries and cars with very different speed-flow curves and travel costs use the same road.

Most models provide for some kind of **segmentation**. Segmentation can be done into many dimensions, such as time of day, purpose, distance, or income. Segmentation by purpose is, for example, supported by the fact that commuters usually have better knowledge of the network.

Furthermore, to make more accurate predictions, **dynamic assignment** can be applied to capture the time-varying nature of traffic. Another important aspect of travel time determination for trips in urban environments is **intersection delay**.

At the end of subsection 9.1.5 of part 3, a few final remarks are made about micro-simulation of road and rail transport, meso simulation, and software.

### 2.3 Data collection, data requirements and scenarios

Model development normally starts with observations or the collection of data regarding the behaviour of the system in reality. The aim is to describe the process in a mathematical model which can ultimately be used to simulate system performance. However, the mathematical model will be based on a theory on how the system works. Once the hypotheses that support the theory are proved right, the model is calibrated by means of available empirical data. This means that the model parameters are estimated so that they correctly reflect the observed data. Subsequently, the model should be validated to check if the outcomes correctly predict the system performance in all other situations. Once the model operates accurately, it can be built into a user-friendly simulation tool.

![Framework research approach](image)

**Figure 2-3: Framework research approach**

The framework in the figure above shows a mutual relationship between the model and the data on the basis of which the model is calibrated. The quality and amount of available data, therefore, directly determines performance of the model. Strictly speaking, no model is better than the data on which it is based.
The cost of collecting data is considerable. It is important, therefore, to review existing data sources prior to designing the model in order to estimate the need for new data collections. Depending on data availability, model requirements and budget constraints, the decision can be made to collect new data. This chapter briefly discusses different types of data and references to a more elaborate description are given in chapter 5 of part 3.

In practice, there may be some overlap between different types of data. Nevertheless, the following classification introduces key sources of existing data which can be used by the designers of a transport model.

1. Land use data population, employment, car ownership
2. Economic/financial data account data, costs
3. Network data GIS-based road map
4. Statistics trade, freight transport statistics
5. Demand surveys O-D patterns, traffic counts
6. Behavioural data household survey, value of travel-time studies
7. Operational data logistics relationship

2.3.1 Land use data
Land use refers to the activity for which land is used. Cities, regions, and countries are all governed by sets of designations assigned to particular parcels of land. Each designation or zone comes with a list of approved uses for the land in question. Land use data is classified into the following broad groups:

A zoning system is used to divide the area to be modelled into manageable bits. One may, for example, choose to aggregate individual households or premises for specific areas of land. Subsection 5.1.1 of part 3 looks at ways of creating a zoning system.

Land use data provides quantitative information and statistics on how zones or areas are used. To estimate the generation and attraction of trips in passenger models, the most important data concerns population characteristics, such as size and employment. On the other hand, the production and attraction of chemical products is best explained by the size of the chemical industry. Subsection 5.1.2 of part 3 provides further details of the collection and application of land use data.

Gazetteer data list properties, addresses or items such that their position is known. A few examples are given in subsection 5.1.3 of part 3.

2.3.2 Economic/financial data
Economic and financial data are expressed in financial terms. It is important to note whether economic value is measured in annual values (prices) or in fixed prices using a specific base year. Annual prices include inflation and often lead to a mistaken indication of relationships with other variables that are also measured in annual values. To prevent this from happening, it is necessary to use a fixed base year and delete inflation from the values.
National account data provide information on domestic income and output as well as stocks and flows of capital. Typical systems of national accounts include national income and product accounts, financial accounts, national balance sheets, input-output tables, and external transaction accounts. In most EU countries, national account data are generally available in a consistent and coherent way over a long period of time. A few of the challenges faced when using national account data for modelling purposes are discussed in subsection 5.2.1 of part 3.

Comprehensive economic data at the regional level are scarcely available, because national statistical offices often do not include them in their data publication. This data is usually compiled in a way that is unsuitable for transport modelling. This means that regional data must be constructed independently, based on the official aggregate data combined with other incomplete data sources.

In most economic models, pricing is the factor that ensures an equilibrium between supply and demand. Price differences prompt changes in the supply and demand of, for example, goods and services. Economic modelling requires a wide variety of prices, such as housing prices, wages, and transport costs. Other examples are given in subsection 5.2.3 of part 3.

Information on travel costs per mode is necessary when modelling passenger and freight transport. Usually, travel costs of passenger transport can be generated from official statistics and fare tables. Information on passenger car travel cost is annually published in many countries. However, cost data of freight transport is much harder to obtain, because businesses are often reluctant to provide this information. Subsection 5.2.4 of part 3 looks at some of the other challenges faced when collecting travel cost data.

2.3.3 Network data

Networks form the basis of every transport modelling assignment. Traditionally, transport networks have been modelled in a relatively coarse manner. However, as congestion and reliability issues move up on the agenda, more accurate and detailed network modelling is required.

When building road networks, modellers should make use of existing sources, such as national road databases in GIS. Road maps of existing models may be used and combined to cover the area of interest depending on the required level of detail. Subsection 6.1.1 of part 3 also looks at other issues involved in gathering road network information.

Modelling bus and rail service networks is a more complex affair than constructing road networks, because they consist of stops, lines and timetables, as well as links. The increase in computational power today has made it possible to apply more realistic timetable-based network modelling to large-scale models. In subsection 5.3.2 of part 3 suggestions are made to find bus and rail network data.

Information on ferry and waterborne transport is normally available from ferry companies. However, since ferry services are included in many traffic models, it may be easier to look to existing models first. Subsection 5.3.3 of part 3 provides an example of how modellers have dealt with this type of transport in the TRANS-TOOLS model.
Information about passenger airline services is available from the Internet, but because of the large number of suppliers it is difficult to implement all airline services for larger modelling areas. It is also difficult to gather information on airfreight services. However, because airfreight services play a minor role in freight transport they are often disregarded. Finally, subsection 5.3.4 of part 3 provides another example of how this type of information is dealt with in the TRANS-TOOLS model.

### 2.3.4 Statistics

Statistics are defined as the regular recording of more general data that is usually collected and published by national or international statistics offices. Key statistics used in transport modelling are briefly discussed below.

Trade statistics describe the movement of goods between countries and regions. They are the basis of freight and transport models, because trade relationships between origins and destinations are the source of all transport movements. Trade statistics contain information on, for example, origins, destinations, goods, modes, and containerisation. Subsection 5.4.1 of part 3 provides more examples, as well as suggestions about data sources available at the national and European level.

Transport statistics describe the movement of transport units, such as vehicles and containers, at specific locations like ports, ferries, and terminals. Trade statistics use net weights (of goods), whereas freight transport statistics use gross weights (of goods plus containers). More information on the availability of national and international data on transport statistics can be found in subsection 5.4.2 of part 3.

National and international passenger transport statistics are available that are relevant to passenger transport modelling. However, they vary from country to country as to quantity and level of detail. Typical examples include ownership of motor vehicles and public transport passenger statistics. A small addition to this can be found in subsection 5.4.3 of part 3.

Commuter statistics describe the spatial relationship between home and work aggregated into catchments due to confidentiality. They can be very useful in passenger transport modelling as a basis for O-D matrices. However, they cannot be applied directly because no mode of transport is given. More details of these statistics are given in subsection 5.4.4 of part 3.

### 2.3.5 Demand surveys

Demand surveys are conducted to obtain an insight into the broad spatial pattern of freight and passenger transport. The data can be used for calibration and validation purposes, and to examine and construct travel patterns.

Road traffic counts are used to estimate, calibrate and validate transport models. The effects of daily variations, misclassifications and survey errors are often underestimated, but if the survey is conducted properly, comprehensive series of classified counts are valuable. Subsection 5.5.1 of part 3 provides additional information on the collection and use of traffic count data.
Road side surveys are brief interviews with drivers using the motorway. Useful knowledge can be obtained for modelling activities, but it remains a difficult task to obtain unbiased information. Some other comments are mentioned in subsection 5.5.2 of part 3.

Public transport counts are used to build O-D matrices for passenger transport models. They are also necessary for validation and estimation purposes. There are many techniques to estimate passenger flows between modes like manual or automatic counts, GPS and fare box data. Because of complexity issues and the risk of collecting insufficient data, this is done less frequently.

Public transport passenger surveys provide information about spatial travel patterns and are useful for the construction of O-D matrices. The data is collected by means of interviews and counts onboard public transport vehicles and at stops.

O-D data from existing models are an important data source in developing new transport models. Even though these data only rarely meet the new requirements, they are a good starting point for estimating new O-D matrices.

2.3.6 Behavioural data

Behavioural data describes the choices made by people in specified circumstances. Main sources include household data or travel diaries. A few brief examples are given below.

Household travel surveys provide household and individual socio-economic data (e.g. income, household size, and car ownership), travel-activity data (e.g. purpose, mode, destination, and timing), and household vehicle data. An extensive overview of the application and collection of household data is given in subsection 5.6.1 of part 3.

Revealed preference data surveys provide additional information about trips that are not registered in household surveys. They are often collected in roadside and passenger surveys as referred to above and in subsections 5.5.2 and 5.5.3 of part 3.

Stated preference surveys consist of observations after individuals have been asked to make abstract choices. In general, they complement revealed preference data. More information is provided in subsection 5.6.3 of part 3.

In value-of-travel-time studies, travel time is expressed in financial terms. This issue is explained in greater detail in subsection 5.6.4 of part 3, where examples and references to relevant studies are given.

Elasticities are used to validate models to test their sensitivity compared to other similar studies found in the literature. However, cross-price elasticities are not equally well analysed and it is very difficult to obtain relevant values without initiating new studies aimed at estimating the elasticities needed. The limitations of working with this type of elasticity are further discussed in subsection 5.6.5 of part 3.
Elasticities in economic models specify the degree of sensitivity of demand for various input factors. It is necessary to know how demand for one type of input increases as the price of another input changes. More information about this issue is provided in subsection 5.6.6 of part 3.

2.3.7 Operational data
For models that consider logistical processes it is necessary to take the availability of data on freight operations into account. Examples of such data are tonne conversion factors to convert commodity flow values to weights, carrier characteristics by commodity type, and operator behavioural relationships, such as working hours and dwell times. Other examples and comments are given in section 5.7 of part 3.

2.3.8 Data collection methods
In subsection 5.8.2 of part 3, a systematic approach to collecting new data is described on the basis of a case study. The case study concerns the development of a transport model for modelling travel behaviour within a metropolitan area.

New methods of data collection are introduced as new technologies are developed and applied. Familiar examples include the use of GPS, mobile phones, and Internet-based surveys to collect data. Subsection 5.8.3 of part 3 provides an extensive elaboration on the possibilities and application of GPS, mobile phones, Internet surveys, and smart cards.

It is important to distinguish between data collected directly and data derived through complicated estimation techniques. Two examples of derived data are activity-based costing in freight modelling and data fusion in demand modelling, described in more detail in section 5.9 of part 3.

2.4 Estimation, calibration and validation
Models, or parts of models like trip generation, distribution, logistics, modal split and assignment models, have many parameters. After specifying and implementing a model, the modeller’s work is not done, because the values of the parameters still need to be estimated and/or calibrated. If this modelling step is not carried out, the results of the model are not very meaningful. Furthermore, if an existing, calibrated model is to be applied to new locations the calibration has to be repeated. Wigan and Southworth (2006) comment as follows: “The calibration issue is one where the intrinsic structure of the model is matched via parameter adjustments to the situation where data are available. Such calibrations often need to be repeated when a model is applied to new locations. If they are not, and parameters are carried from one situation and location to another, the model may be excellent but the application substantially deficient - and certainly ‘wrong’ in a practical way.”

After estimation and calibration, validation takes place. According to Wigan and Southworth (2006), validation is a far more slippery process and considerably less easy to address than calibration. Validation is more about confirming that the model represents real world structures in some fair approximation. If the modeller is not satisfied with the validation, he will have to redo the estimation and calibration. It is, of course important for the modeller to
determine the causes of the deviation from the desired results before re-implementing the estimation and calibration steps.

**What is estimation, calibration and validation exactly?** A brief description of these terms is given below. For more details, please refer to the State-of-the-Art report (part 3). Sections 4.3 and 4.4 of part 3 looks at a few general aspects of estimation, calibration and validation. Sections 6.2, 7.2, 8.2, and 9.2 of part 3 describe the estimation, calibration and validation procedures for freight, passenger, economic and assignment models.

**Estimation:**
Estimation consists of fitting a model using data to explain uncertainties. The three main estimation methods are Likelihood Estimation (MLE), Ordinary Least Squares (OLS) and Maximum Entropy. These techniques have traditionally been used in trip generation, trip distribution, modal-split and assignment models. Initially, estimation of these models took place sequentially, but nowadays two or even more models can be estimated simultaneously.

**Calibration:** Calibration is an iterative procedure in which model output is matched to observed data. It is an important part in any applied transport model. Even after ambitious estimation, a model may fail to reflect various observations about the real-life transport system. For instance, this may be the case for certain aggregated travel volumes or link flows. This is the reason why calibration takes place.

There are basically three related approaches:
- Adjust the constants of the models or introduce specific adjustment factors in order to increase the match with observed data.
- Calibrate the network and zone connectors in order to match modelled traffic with counted traffic.
- Substitute or complement model estimation by more or less advanced heuristic procedures used in matching the model with observations.

The first approach is used in most demand modelling contexts, e.g. when nested logit models are estimated on the basis of survey data and other aggregate data is available. It is easy to produce a good result with a large number of adjustment factors. However, the adjustments are not explained and in a forecasting situation, these factors are taken to be constant over time. Ortúzar and Willumsen (2001) warns against using a large number of so-called K-factors in aggregate travel demand modelling.

Network calibration is conducted on the basis of the assignment results. If the network information, for instance, is based on general road maps etc., local speed limits may not be available. During calibration, the network can then be adjusted directly by an inventory of local conditions or indirectly through adjustments until counts and output fit. A divergence between modelled and counted traffic may also arise from incorrect zone connectors or too large zones loading traffic to the network in an inappropriate way.
It is important to note that calibration is not an exact science. It relies on experience to know what kind of precision to expect from a given model type. Furthermore, calibration should not be used to cover up errors occurring in other parts of the model. Given a problem, it is important through validation to detect the source of the differences between projections and observations before adjusting the model.

**Validation:** Validation is the process of quality control. By validating a model system, one tries to assess the credibility of the forecasts to be produced by the system. This is not an easy task and it is often somewhat neglected in practice.

Thorough validation of a model or model system involves several steps. The following scheme may serve as a checklist for analysing how well a system functions and how well it serves its purposes:

- **Practical validation:** The first step should be to make sure that the system is correctly modelled (system limitations, exogenous and endogenous variables, policy handles, fit for purpose, etc.). Are the necessary resources available and is the model complexity required for answering questions from model users?

- **Theoretical validation:** The next step has to do with the theoretical basis of the methodology: equilibrium or disequilibrium, static or dynamic, degree of integration of sub-models, are casual relationships reasonable and well-modelled? This step involves a quality control before the model is implemented and applied.

- **Internal validation:** This step focuses on the results of the estimation and calibration. Does the model reproduce input data with reasonable accuracy without relying on too many adjustment factors? Are the parameters of the right type and statistically significant? Is the responsiveness to changes in explanatory variables defendable (as revealed by sensitivity tests or implied elasticities)?

- **External validation:** This final step deals with the forecasting ability of the model when applied in practice. Can the model reproduce other data than that used for its estimation and calibration (e.g. traffic counts on road links)? Are the elasticities of the model compatible with the majority of other studies in the literature? Can the model foresee the impact of a certain policy package? The ultimate test of the forecasting ability can only be analysed if before-and-after data related to a policy package are available. External validation is only rarely done, as is a systematic comparison of alternative models in one and the same spatial context.

Ideally, validation should be conducted on the basis of a sample not used for estimation or calibration. However, due to time restrictions this is rarely possible. The validation sample is most often a representative sub-sample of the original sample, which was not used for the estimation and calibration of the model. The outcomes predicted by the model on the validation sample are then compared to the actual outcomes for the validation sample.

In general, validation can also be divided into formal and informal tests. Informal tests consist of comparing expectations and signs or relative sizes of parameters. It is also useful to
compare VTTS estimates or demand elasticities with those reported in other studies. An example of a more formal test is the percentage root mean square of the error used to assess whether modelled traffic approximates counts sufficiently. Other examples can be found in, e.g. Vuk and Hansen (2006).

How accurate are the models? Are the results of the models acceptable? These two questions are very important and underline the importance of validating models. If no one believes the results, the model will have no value. It is important to report all the statistical tests and the theoretical understanding of the various models, but these measures are irrelevant if the model cannot be proved to provide reliable answers to the questions they were designed to answer.

There is no fixed procedure for evaluating economic models. Validating also crucially depends on the type of model. Macro-economic models that predict future development of a national economy should be able to describe the main trends accurately, whereas some strategic models should be accurate only in relative terms, for example, to indicate which of several effects are likely to be the most important consequences of a new policy. This type of outcome is the most common in economic modelling. The models provide answers as relative changes in key variables, i.e., with less focus on absolute values. This is particularly the case for SCGE modelling, even though some CGE models are designed to answer absolute questions as well.

The best way of validating a model is to use it for several purposes, to be careful in interpreting the results, and to compare them to other similar studies. Are the results within an expected range of values and does the output look similar to the results of other models?

### 2.5 Uncertainties in models

When models are used to analyse a policy issue or investment, they are tested against different scenarios. Two possible scenarios are the “do something” and the “do minimum” scenarios. In any scenario, it is necessary to decide on how the model deals with uncertainties. The largest amount of uncertainty in terms of forecasting arises from derived data and the possible instability of patterns under the base scenario. There are many other sources, but in practice, they seem to have a smaller effect. These include:

- Data measurement errors;
- Inaccurate network data;
- Self-selection bias in reported data;
- Statistical uncertainty;
- Computational uncertainty in either simulation or optimisation;
- Model specification, e.g. omitted variable bias or the fact that the model does not reflect causal relationships accurately;
- Uncertainty due to solution algorithm;
- Aggregation and transfer errors.
For some of these sources, methods exist to quantify the uncertainty, e.g. imputation for data uncertainty, Monte Carlo simulation, bootstrapping to understand estimator uncertainty, and robust estimation to minimise the effect of specification errors.

As far as uncertainties in the model output are concerned, it is relevant to note that total uncertainty has another component which is termed variability. It is important to bear in mind that the modeller can work on reducing uncertainty, but cannot reduce the variability inherent in a transport system.

An often used approach to reducing uncertainty in forecasting is to apply pivot-pointing of demand matrices. It minimises the errors by focusing on changes relative to a base. Two reasons why changes relative to a base may give more precise forecasts are that base year demand matrices obtained from observations (counts, surveys etc.) usually have more accuracy and that errors in a model can cancel out when only proportions are modelled.

We will not discuss all different approaches: factorial, incremental or additive pivoting. For most purposes, the factor pivot-point method will be adequate. The procedure applies the ratio of model outputs for base and forecast situations as a growth factor to the base matrix, i.e. in a given cell the predicted number of trips $P$ is reflected by:

$$ P = B \cdot \frac{S_f}{S_b}, $$

where:

- $B = \text{observed base 2004 trips from the base matrices}$
- $S_b = \text{base year synthetic trips}$
- $S_f = \text{future year synthetic trips}$

Two important questions are how to deal with zero cells and extreme growth.

### 2.6 Linkage to other models

Models are developed with specific purposes in mind. The model structure and level of detail are geared to achieving these specific purpose. However, sometimes it makes sense to look at the broader context of the issue and the specific place of the model within this context. Consider, for example, the geographical coverage or the link to other aspects in the transport ‘system’. Tendencies that are not directly related to the geographical area or transport aspect covered by the model can have a large impact on the outcomes. It is not always possible to cover all aspects with one model. If it is possible, it is very costly, so it would make sense to consider linking the model to other models. In this way, the model will achieve its objectives cost-efficiently. The geographical coverage and details of variables and the creation of a model system are discussed in the following sections.

#### 2.6.1 Geographical coverage and detail of variables

Most models are developed with one scale in mind, e.g. international, national or regional travel. Models can be typified into decision level and different scales of modelling. Mixing and linking of models with different scales, e.g. regional and national models could potentially be a cost-efficient way of incorporating the benefits of the different scales and improving modelling capabilities. However, in practice it is often complicated and prevented by inherent differences in the models.
The modeller has an early choice of coverage and spatial resolution to match the objectives. If, for instance, the scheme to be tested includes effects on international flows of passengers and freight caused by major changes in cost structures and infrastructure, the model must be scaled to at least European level.

In principle, greater accuracy can be achieved by using a more detailed zoning system. To take advantage of the fine spatial resolution, however, accurate and consistent data need to be available at fine spatial resolution. When data (O-D patterns, population, employment, income, etc.) have to be approximated to match the fine zonal system, the achievements of a fine spatial resolution is doubtful. To achieve the same accuracy in the description of an O-D pattern, the sample size requirements increase by number of zones. Therefore, it also reflects a conflict between accuracy and cost. In practice, it is often professional judgement to choose a zonal system that considers requirements for accuracy in network flows, computing time, and data constraints necessary to meet the objectives of the study.

Depending on the scale of modelling, few simple guidelines for spatial resolution are available. In models at global level, a zoning system based on countries or even aggregates of countries should be sufficient. Models at European level are often based on NUTS 2 or NUTS 3 since accurate network flows are rarely the primary objective. While national models are often based on administrative divisions or subdivisions, e.g. municipalities, the zonal system of regional and local models usually requires a much finer zonal system to estimate network flows and congestion effects accurately.

If the model focuses on a smaller area within the study area, which is often the case, then different levels of spatial resolution are needed. This is, for instance, the case with corridor models, where the focus is on traffic travelling in the corridor or along the screen line. Thus, a fine zonal system could be defined in and around the centre of interest and reduced in detail by distance to the centre of the model.

The following levels can be distinguished:

- Global models
- European models
- National model
- Regional models
- Metropolitan and urban models
- Corridor models

The first four levels mentioned are worked out in the following schemes. Examples are given on policies and events occurring at different levels. Here we see for instance at global level that a shift of trade can occur. If this means that the Port of Rotterdam will receive 50% more container flows due to an increase in trade between Europe and China, this will also have an impact on the regions near Rotterdam where distribution by inland modes take place. Hence, a global event can have impact on all underlying levels. Another example, if Switzerland were to decide to double the toll on its road, this event can be observed at a European level and have an impact on a country like France, which will see much more transit traffic from the
Benelux to Italy. So an event taking place at a European level can also have an impact at the national and regional level.

It is not easy to link a global model directly to a regional model. It is easier to link a global model to a European model, because the level of detail of regions, goods and other aspects are closer to each other. Each lower level covers a smaller area and has a more refined level of detail of variables. In general, it can be stated that the best way of matching models is to connect them to the next higher level. In some cases however, if four levels have to be combined, this may lead to too high costs.

Model examples are given in the following figure of available models at different levels. As regards the national and regional level, Dutch examples are provided.

![Figure 2-4: Examples of policies and events covered at different levels](image)

![Figure 2-5: Existing models at different levels of policy making (models can be found in MDir)](image)
One can identify different users/policy-makers at the different levels of models, for example at the regional level: the regional government, chamber of commerce, regional branches of the Ministry of Transport. The national authorities focus on models that cover all regions of a country. Usually, it is ensured that regional and national models are compatible, meaning that scenarios are similar and, moreover, that data is similar too, also on a European level. More information on this issue is provided in section 12.2 of part 3.

2.6.2 Creating a model system

Only under certain conditions can existing model systems be linked into a series of models in a cost-efficient way. This is nonetheless done to connect different aspects of the transport system, cover a larger study area, or test complex schemes. In practice, linking existing models is a matter of transferring data and model results between the models. The linking of scale can be an integrated part of the new model system and will require a well-defined and organised structure. How to link models can best be explained by an example. The figure below shows the model linkages found in the TRANS-TOOLS model. First of all, one can see that the assignment input from the freight model and passenger model is needed. If the assignment is made by using the results of just one of the two models, this would lead to an underestimation of the link loads, and subsequently fewer bottlenecks would be found. Also, travel times and costs are influenced by these bottlenecks. Travel times and costs are input in the passenger and freight models, as shown by the conversions in the figure following the assignment model. So even if an assignment is not the desired end result of a study, and one only needs the O-D flows, it might still be useful to connect the different models.

![Diagram of model linkages found in the TRANS-TOOLS model](image)

**Figure 2-6: Overview of the principles of the TRANS-TOOLS Model**

Apart from the direct impact of travel times and costs produced by the assignment model on the freight and passenger movements, there is also an indirect effect. Because of the bottlenecks, the accessibility of a region may worsen. This will, in turn, have an impact on the economic activity of that region. This economic development is input in the freight and...
passenger models. In the figure, this is shown by a feed-back loop from the assignment model to the economic model and then as input in the freight and passenger model.

Finally, the figure also shows an impact model that uses the output of an assignment model. The number of vehicles on a link, for instance, determines emission and safety levels on the link. More information on this issue is provided in section 12.3 of part 3.

2.7 Stakeholders and institutional environment

Carrying out a policy analysis involves applying and using a set of analytic tools and approaches to make explicit the costs and benefits (broadly-defined), trade-offs, and other impact of possible actions (policy measures) by policy-makers. Thus, policy analysis helps policy-makers arrive at decisions in an uncertain world by structuring the problems, developing alternatives for dealing with these problems, and making explicit the consequences of their decisions and actions. In doing this, it uses a variety of tools to develop and present information to the different stakeholders in the policy-making process in a manner that helps them come to a decision.

The policy-analysis approach is based on a description of the system covering the relevant policy domain (see figure below). The system description is a conceptual model of the system representing the policy domain. The model of the system (1) defines the boundaries of the system – what is included and what is excluded from the system, and (2) defines the structure of the system – the different elements making up the system and the links between them.

Figure 2-7: Elements of the policy analysis approach

Acting on the system are two sets of forces: external forces, forces that are outside the control of the actors in a given policy domain, and policies that are within the control of actors in this

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same policy domain. Both sets of forces are exogenous to the system and affect the structure of the system (and hence, the outcomes of interest to policymakers and other stakeholders).

Over time, both the external forces (for example, the economic environment, technology developments, and the preferences and behaviour of people) and policy may change. Changes in the external forces can bring about changes in the system by redefining the boundaries of the system, changing the system elements, their functioning, or the links between them. This, in turn, will change the outcomes of interest. Thus, the external forces as well as their effects on the system are both highly uncertain. Policy changes are less uncertain, but their effects on the structure and functioning of the system, and on the outcomes of interest are often highly uncertain. Thus, uncertainty is ever present in a policy analysis.

Typically, scenarios are the analytical tools used to represent and deal with these uncertainties. Each scenario is a description of one possible future state of the system. Scenarios do not forecast what will happen in the future; rather they indicate what can happen. Finally, scenarios do not include complete descriptions of the future system; they include only factors that might strongly affect the outcomes of interest.

Policies are the measures that actors in the policy domain can take to affect the structure and/or functioning of the system in ways that bring about desired changes in the outcomes of interest. In terms of national policies, the problems and benefits generally relate to broad national goals—e.g., trade-offs between national environmental, social, and economic goals.

The performance of policy measures put in place to achieve a given policy goal is measured using multiple criteria. These criteria should relate to the outcomes produced by the system and be of interest to policy-makers. These criteria are called outcomes of interest.

The choice of policy depends on measuring the outcomes of interest relative to the policy goals and objectives, identifying the preferences of the stakeholders, and making the necessary trade-offs among the outcomes of interest given these preferences. The exploration of the effects of alternative policies on the full range of the outcomes of interest under a variety of scenarios, and the examination of trade-offs among the policies requires a structured analytical process that supports the policy-making process.

2.7.1 Policy issues, modelling, data and responsibilities
As shown in the previous section, the first important question to be raised at the beginning of the process is which policies should be addressed and following from this, which data should be included. Starting with the policies, the work should be structured along a logical path that extends from these policy issues to questions about indicators in order to measure the effects of policies, and finally the basic variables to derive the indicators. From the policies selected, the most appropriate indicators should be selected. To calculate the indicators, data variables are needed. In order to obtain these variables, specific data have to be collected and methods and models defined in order to fill the data gaps. This logical path is illustrated in the ETIS pyramid in the figure below as developed in the ETIS-BASE project.
In this process, the models are only applied when data is not available. Furthermore, the models are only applied in order to fill the data gaps; i.e. where collected data should be used and the definition of the models should be adjusted to reflect data availability. In cases where data availability is poor, or the subject being studied is very specific, data will have to be collected on an ad-hoc basis. If the data is needed on a structural basis, the decision may be taken to include the required data in the statistical programme. This is, however, a long-term solution.

In terms of forecasting, models are of course always needed. However, a pivot point method may be chosen if base-year O-D flows are available.

Different types of data are needed in transport modelling:
- Trade data
- Passenger transport flows
- Freight transport flows
- Infrastructure use and characteristics
- Socio-economic data
- Impact data

These data can be obtained from different sources, including:
- Customs control
- Statistics office
- Ministries
- Private sector (example: toll roads, airlines, inter-modal transport)
- Transport sector (private or state: railways, road haulage)

When starting or restructuring data collection, synergies may be found. Some data will be needed by various Ministries and hence can be exchanged. Examples include:
- Economic indicators
- Trade figures
• Population figures

The key benefit is that only one official registration is used so any misunderstanding can be avoided. It is important that responsibilities should be described very clearly.

In the ETIS-BASE project, a major European database development project conducted for DGTRRN, a combination of data collection and model application was used to set up a comprehensive European database (http://www.iccr-international.org/etis/). By way of example, the table below lists the typology of the collected ETIS data along with the different sources used.
**Table 2-1: Data collected and included in the ETIS pilot**

<table>
<thead>
<tr>
<th>Category of data</th>
<th>Type of data included3</th>
<th>Data sources4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-Economic</td>
<td>GDP, participation in the labor market, population size and age distribution,…</td>
<td>EUROSTAT (NEW CRONOS, REGIO, COMEXT, GISCO), EUROGEOGRAPHICS (SABE), Corine land cover, World Bank, IMF (International Monetary Fund), WTO (World Trade Organization), OECD (Organization for Economic Co-operation and Development), Worldfact Book (CIA database), project results including SCENES,…</td>
</tr>
<tr>
<td>Freight demand</td>
<td>Transport chain OD (origin-destination) matrix, transport volumes, number of truck movements, origin and destination of cross border traffic, combined transport, trade volumes, tons of shipments, commodity types…</td>
<td>EUROSTAT (NEW CRONOS, COMEXT), CAFT (Cross Alpine Freight Traffic), National statistical offices, port authorities, UN (United Nations Trade data), Freight operators (ICF International Coach Federation, UIRR International Union of combined Road-Rail transport companies), Project results including INTERMODA and SPIN, diverse websites,…</td>
</tr>
<tr>
<td>Passenger demand</td>
<td>O-D matrix, number of passengers per day, trip purpose, mode of transport,…</td>
<td>EUROSTAT (NEW CRONOS), project results including DATELINE, IATA (International Air Transport Association) Digest on Statistics, UN-ECE (United Nations Economic Commission for Europe Road Transport Censuses), Official World Airways Guide, Airline Coding Directory, ferry statistics, HAFAS (online German railway schedule information system), EUROCONTROL flight schedule information, National passenger O/D matrices, UIC (International Union of Railways),…</td>
</tr>
<tr>
<td>Transport infrastructure network</td>
<td>GIS data (nodes and links), Kilometres of network, number of railway or motorway lanes, airport capacity, quality of infrastructure…</td>
<td>UN-ECE, UIC, EUROSTAT (GISCO), EU project results like TEN-STAC and GETIS (Geo-Processing Networks in a European Territorial Interoperability Study), ICAO – (International Civil Aviation Organization) statistics, Official Airline Guide (OAG), EUROGEOGRAPHICS, EUROCONTROL (European Organisation for the Safety of Air Navigation), Computer Reservation Systems, government internet websites, tariff database of consolidator (air tariffs) …</td>
</tr>
<tr>
<td>Freight services and costs</td>
<td>Transport schedules, Price per ton, equipment deployed and detailed information per vessel/vehicle, operators,…</td>
<td>EUROSTAT (GISCO), Transport operators, shippers, Ports and Terminals, Business directories, project results including RECORDIT, SPIN and GBFM Freight Modelling Project,…</td>
</tr>
<tr>
<td>Passenger services and costs</td>
<td>Flight, rail and ferry schedules, ticket prices, airport taxes, access times, routing,…</td>
<td>Official Airline Guide (OAG), EUROGEOGRAPHICS (SABE), websites of ferry and rail companies, timetable for passenger ferry services, international rail timetables, tariff database of a consolidator for air tariffs, UIC, EUROCONTROL, ICAO, HAFAS, …</td>
</tr>
<tr>
<td>External effects</td>
<td>Emissions, accidents, injuries,…</td>
<td>EUROSTAT, national data sources and publications, project results including COMMUTE, RECORDIT, TEN-STAC, INTERNAT, MEET</td>
</tr>
</tbody>
</table>

In many countries, a combination of data collection and modelling is used to obtain the information needed for policy-making purposes. On this point, a distinction is to be made between the statistics office or other providers of source data and the institutions responsible for the modelling and supply of the modelling results. The modelling part is often done by independent researchers. The models developed will then be owned either by these independent researchers or by the Ministry. It may be useful to engage an in-house research institute at the Ministry. This will ensure an independent study with fewer budgetary

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3 This column does not represent the complete list of data types included into the ETIS pilot (for the complete list see http://www.etis-eu.org).

4 This column does not represent the complete list of data sources included into the ETIS pilot (for the complete list see http://www.etis-eu.org).
constraints. Moreover, there will be direct contact between civil servants and policy-makers. And last but not least, both the study and the findings can be better monitored so that the answer will match the ‘policy demand’. In this case, it is important that a clear strategy should be chosen because limited capacity will be available that should be used efficiently. If the modelling is contracted out to consultants, capacity will be much more flexible.

2.8 Intellectual property rights
The actual work of constructing a transport planning model will, in most cases, be contracted out to a commercial company. A clear working plan should be available first as a basis for the consultants to submit a financial proposal. The regional government will need to draw up this working plan and be very clear about whom will be the owner of the transport model. The intellectual property rights will have to be specified in the contract. If this is not done accurately beforehand, the regional government may be forced to work with the same consultants for all follow-up work and new developments.

We would recommend addressing intellectual property rights (IPR) issues early in the modelling process and developing a clear policy. The assignment of IPR will always be an issue. There are three benefits of developing and communicating a clear policy early in the life of the project: it will improve the contract negotiation process, save time when addressing the concerns of public and private parties, and help avoid protracted negotiations as a result of contractual misunderstandings. There are also three drawbacks in terms of costs: the time spent by staff in drafting the policy, private partner objections causing delays, and potential loss of participation by qualified firms.

It also important to create a policy to specifically address software and technologies contributed to, improved, and developed during a project. When developing a new approach or dealing with a new subject, it could well be the case that the consultant devises a new methodology or software which could be used for other purposes as well. These aspects need to be described in advance.

Finally, it is essential that a policy should be developed to manage the data collected once the project is implemented. This is especially important in ITS projects.

2.9 Software

General
A major issue faced by transport analysts and modellers is the development, control and management of large complex databases. To support transport analysts, a wide range of commercial software packages is available to help them manage large databases. Over the years, software has substantially improved to provide problem solutions and alternative problem solutions for engineers, planner and analysts to consider, thus increasing productivity and reducing the costs associated with these analyses. Computerised tools have thus become a necessity for any transport professional. The abundance of software packages available on the market raises many practical questions for users and managers, such as:
What program should I buy?
Will this program cover my specific needs?
Is there a program that can do it all?

In this handbook, we specifically do not wish to evaluate the different software that is commercial available. We will limit ourselves instead to providing a brief outline of historical developments and listing general criteria for selecting software. Apart from the choice for specialised transport modelling programmes, in some cases models are available in a programming language such as Delphi, C++, etc. In general, this allows for more flexibility than the specialised programmes, but will be more expensive.

History

Within Europe the application of computerised transport models started in the UK. TRL (Transport and Road Laboratory) started in the early 1970s with the RRLTAP suite and, for strategic studies, the CRISTAL set of equilibrium models. Later, efforts were directed towards two (seemingly opposing) directions: application in the “European conditions” of the more sophisticated disaggregate demand models that were first developed in the US, and “Simplifications” of the conventional models, to achieve economies in the data required and the computer power, or simply the expertise required.

In the first category, the Hague Consulting Group, the Free University of Amsterdam, and the University of Karlsruhe in Germany are prominent European researchers. On the other hand, the drive to produce simplified models was directed by the Organization for Economic Co-operation and Development (OECD) in Paris. The national reports by seven of its member countries (Belgium, Ireland, United Kingdom, Finland, Denmark, Canada, Spain) revealed a concentrated effort at model simplification, directed towards five types of simplification:

- Restriction to two trip purposes (home/work, and home/other);
- Adopting a less detailed level of traffic zoning (e.g. regional rather than more detailed);
- Adopting “once- through” tree building and loading algorithms;
- Simplifications to the model formulas in order to roll all three first steps of the four-step process into one, and
- Simplifications related to the data collection methods and the use of models developed in other urban areas.

These five simplifications were – and to some extent still are – the basis for a large part of the regional transport models. The traditional and sequential “four-step process” is still used for the majority of planning purposes. Several transportation planning software packages have been developed and are currently used to automate the four-step process. Examples include CUBE, EMME/2, MEPLAN, MINUTP, OMNITRANS, TP+, TRANPLAN, TRANSCAD, TRIPS and VISUM.

There exists an important distinction between transportation planning models and transportation planning software packages. Models serve as analysis tools for transportation

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5 Large part of this section is based on Boile and Ozbay (2005)
planners and they aid decision-makers in evaluating alternative proposals for a transportation issue. Models are basically mathematical equations that are established by research and practical efforts. They represent some aspects of traveller behaviour or transportation system and are important because transportation plans and investments are based on what the models say about future travel. Model estimates are the basis for transportation plans and are used in major investment analysis, environmental impact statements, and in setting priorities for investments.

A transportation software package is a tool to implement transportation models already developed. Usually, a transportation-planning model is made up of several sub-models (e.g. trip generation, trip distribution, mode choice, trip assignment). Mathematical models can be used to represent each of these sub-models. These mathematical models are then implemented in various transportation planning software packages.

**How to choose a software package?**

There are many considerations when selecting a software platform for transportation modelling. These can be divided in technical criteria and, secondly, criteria which describe the fitness for purpose. Important technical questions/criteria are:

- How does it interface with other software?
- How does it store data and what are the input-output routines?
- What is the processing speed?
- How does it build highway and transit paths?
- What is its GIS and spatial analysis capabilities?
- How does it edit the network?
- How does it generate reports?
- How are different components of the model tied together?
- How are scripts customised?
- How does it calculate matrices and link flows?
- What are the component applications?
- What is the operating system?
- How is everything displayed?
- How is it tied into other transport models in the region/country?

But secondly, a review is needed to see whether or not the functionality of the software is capable of dealing with the policy issues on hand. These could be questions like:

- Capability of modelling traffic operations, analysis, review, and application of traffic data to the operation of transportation facilities?;
- Capability of modelling traffic design that incorporates the determination of travel patterns and parking characteristics of transportation users in the planning and design of transportation facilities?;
- Considering the application of land use and economic data in the development of policies for financing transportation improvement?; and
Capability of modelling issues such as the development of toll roads, the evaluation of measures for congestion containment, the noise and pollution impact of urban traffic, the development of transit services, and freight planning?

Of course, financial aspects play another role in the considerations of choosing software.
3 Introduction Part 2: Policy Issues and Models

This part of the handbook addresses the modelling issues from the point of view of the users, i.e. the policy-makers. The aim is to describe the process starting from the policy-maker who encounters “problem” and needs a model to resolve it. The question of whether a model is needed to resolve the issue will not be dealt with here. We assume a model is needed for various reasons (such as the recurrence of policy issues, or the ability to reproduce the same results, etc). A short description is given of the background to individual policy issues as they are addressed in practice. Each paragraph dealing with a policy issue is structured as follows:

1. context of the policy issue
2. organisation of the modelling
3. modelling process

In the modelling process, we try to link this to passenger demand modelling, freight demand modelling, assignment models, economic models and impact models, as these are listed as specific modelling areas. Moreover, a list is provided of existing models that can be used as a reference. In addition, a link to best practice examples is included.

In the next 16 paragraphs, the following policy issues will be described according to the above-mentioned structure. It should be stressed that this is not an exhaustive list and instead serves merely as an example:

1. Strategic Mobility: this entails an overall view of the long-term development of the mobility of freight and passenger transport in the infrastructure network, including environmental aspects and energy-related issues.
2. Demand Analysis: this covers the effects of a policy on passenger or freight transport demand, including pull and push measures such as taxation and subsidised transport.
3. Land use planning: this concerns the distribution and intensity of trip generating activities in urban areas, using as input the aggregate information on growth generated by an aggregate economic forecasting activity.
4. Industrial Location Decisions: this concerns the effects of industry localisation and on mobility patterns.
5. Ex-ante policy analysis: models are necessary to evaluate policy before it is introduced, the model needs to be adjusted to be better able to address the policy issue.
6. Investment Analysis: this is a bit more focused than the previous ex-ante policy analysis. It usually concerns investments in infrastructure and policy-makers want to know whether the investment is feasible from a societal/economic point of view, private investors are interested in the financial feasibility of the project.
7. Modal shift: policy-makers are interested in freeing up network capacity by shifting from one mode of transport to another.
8. Infrastructure planning: this concerns the optimal layout of a network and observes where additions to the network need to be made.
9. Pricing: in order to make maximum use of the capacity of infrastructure networks, policy-makers are focusing on pricing and introducing a system of variable rather than fixed taxes.

10. Road Traffic Management: this concerns the safe and efficient movement of passenger and goods transport on the road network, and includes the planning aspects of transportation engineering in relation to urban planning, and involves technical forecasting decisions and political factors.

11. Urban Public Transport: although similar to the previous policy issue, it concerns public transport planning and requires different techniques and models.

12. Rail transport planning: although similar to road traffic management, it concerns the planning of the rail transport system and requires different techniques and models to those need for the previous 2 policy issues.

13. Intermodal solutions: policy-makers often require intermodality, or co-modality as it is now called by the European Commission, where different modes are combined.

14. Project Impact Assessment: this concerns the impact of specific transport projects. The investment in, for example, a terminal or port is investigated to see if it has had the desired effect.

15. Safety and the environment: the external effects of transport are increasingly becoming a concern of policy-makers, usually these are included in cost-benefit analyses carried out for transport project assessment purposes.

16. Capacity utilisation: this concerns the capacity use of infrastructure networks to see whether solutions are available.

The MDir (Appendix A: Modelling Directory) gives an overview of a large number of existing transport models in Europe. In the table below we have listed the models according to the policy issue for they were mainly designed.

Table 3-1: Transport models in MDir by policy issue

<table>
<thead>
<tr>
<th>Policy issue</th>
<th>Number of models included in MDir</th>
</tr>
</thead>
<tbody>
<tr>
<td>strategic mobility</td>
<td>80</td>
</tr>
<tr>
<td>demand analysis</td>
<td>12</td>
</tr>
<tr>
<td>land use planning</td>
<td>25</td>
</tr>
<tr>
<td>industrial location decision</td>
<td>1</td>
</tr>
<tr>
<td>ex-ante policy analysis</td>
<td>13</td>
</tr>
<tr>
<td>investment analysis</td>
<td>3</td>
</tr>
<tr>
<td>modal shift</td>
<td>2</td>
</tr>
<tr>
<td>infrastructure planning</td>
<td>66</td>
</tr>
<tr>
<td>Pricing</td>
<td>13</td>
</tr>
<tr>
<td>traffic management</td>
<td>20</td>
</tr>
<tr>
<td>public transport planning</td>
<td>27</td>
</tr>
<tr>
<td>intermodal solutions</td>
<td>2</td>
</tr>
<tr>
<td>project impact assessment</td>
<td>9</td>
</tr>
<tr>
<td>environment and emissions, safety</td>
<td>17</td>
</tr>
<tr>
<td>capacity utilisation</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>304</strong></td>
</tr>
</tbody>
</table>
The table below shows the number of models included in MDir by country. The first item “non-specific generic models” concerns general models that are generally applicable and can be used in a specific study area (such as the EMME/2 model or VISUM). Multiple country models are also included, covering all or parts of Western Europe or the EU as a whole (including EU15 and EU25; please note that an EU27 model is under construction for freight). The models described range from those developed in the late 1970s, when the first computerised transport models were constructed, to those developed recently. The choice was made to keep all models in the MDir in order to learn from past experience. We have the impression that about 85 to 90% of transport models in Europe are included (this is higher for the “old” member states). As shown in the table below, the “old” member states pay more attention to freight modelling compared to the “new” member states, where transport modelling focuses on passenger transport. The majority of models has been constructed for passenger transport analysis only. Models dedicated to freight can be found mainly in the Netherlands, Germany and the UK. Models that cover both passenger and freight are a minority, however, in Denmark and the Netherlands these form a significant part of all models and models covering the EU.

Table 3-2: Freight and passenger models by country

<table>
<thead>
<tr>
<th>Non-specific generic models</th>
<th>Unknown</th>
<th>Passenger</th>
<th>Freight</th>
<th>Both</th>
<th>Total</th>
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</thead>
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<tr>
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<td>1</td>
<td>5</td>
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<td>27</td>
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<tr>
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<td>9</td>
<td>11</td>
<td>0</td>
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</tr>
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<td>10</td>
<td>3</td>
<td>4</td>
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</tr>
<tr>
<td>UK</td>
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<td>8</td>
<td>7</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>Denmark</td>
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<td>4</td>
<td>5</td>
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<td>5</td>
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<td>1</td>
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</tr>
<tr>
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<td>4</td>
<td>1</td>
<td>11</td>
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<tr>
<td>Switzerland</td>
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<td>0</td>
<td>2</td>
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<tr>
<td>Austria</td>
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<td>0</td>
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<td>Poland</td>
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<td>0</td>
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<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Western Europe partly</td>
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<td>3</td>
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<tr>
<td>Eastern Europe</td>
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<td>1</td>
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<td>9</td>
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<td>Non-European countries</td>
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<td><strong>Total</strong></td>
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<td><strong>155</strong></td>
<td><strong>69</strong></td>
<td><strong>38</strong></td>
<td><strong>304</strong></td>
</tr>
</tbody>
</table>

In the table below, regional model details are given for the countries included in MDir. It can be observed that the majority of models has been constructed at an urban/regional level of
detail (102 models in all). A number of regional models focus solely on the national level without considering international flows (92 models in all). Some national models also include international flows to and from their country (43 models). These are usually freight models, as in some cases international freight transport may account for 50% of total freight transport. The last category is that of the “truly” international models that cover more than one country and describe traffic flows within and between these countries (all at the same level).

Table 3-3: Transport models by country according to regional detail

<table>
<thead>
<tr>
<th>Non-specific generic models</th>
<th>Not specified</th>
<th>urban/regional</th>
<th>national models/regional</th>
<th>national models incl. international</th>
<th>International models</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-specific generic models</td>
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<td>0</td>
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<td>0</td>
<td>38</td>
</tr>
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<td>4</td>
<td>38</td>
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<tr>
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<td>1</td>
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</tr>
<tr>
<td>Netherlands</td>
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<td>32</td>
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</tr>
<tr>
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<tr>
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<tr>
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<td>6</td>
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<td>12</td>
</tr>
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<tr>
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<tr>
<td>Sweden</td>
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</tr>
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<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Western Europe partly</td>
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</tr>
<tr>
<td>Eastern Europe</td>
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<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>EU</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Non-European countries</td>
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<td>5</td>
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<tr>
<td>Total</td>
<td>39</td>
<td>102</td>
<td>92</td>
<td>43</td>
<td>28</td>
<td>304</td>
</tr>
</tbody>
</table>

Further details of the models included in MDir are given in annex 3, and can also be accessed via the Access database on the website. Having described the transport models and their link to the policy issues, we will now look at the 16 specific policy issues.
3.1 Strategic Mobility

3.1.1 Policy needs

Policy-makers are interested in general mobility developments in a region, country or a group of countries (such as the European Union). In most cases, general figures on the transport developments, such as the number of tonnes or tonne-kilometre transported in case of freight transport or the number of passengers or passenger per kilometre, will form the first analysis of transport. Usually this type of analysis is supported by mode and type of goods for freight transport and trip mode and trip purpose for passenger transport. Another example are ports, where the throughput of the total number of containers is an important fact, especially when compared to the throughput achieved by neighbouring competing ports.

As shown in the figure above, the growth of road transport often relates to sustainable mobility, because the mode that has seen the highest growth is road haulage. A similar pattern is found for passenger transport. Sustainable transport is defined as any form of transport that minimises emissions of carbon dioxide and pollutants, ranging from public transport, car sharing, walking and cycling to technology, such as electric and hybrid cars and bio diesel. In freight transport, intermodal transport savings programmes have been initiated to support sustainable transport.

The concept of sustainable transport is a response to some aspects of transport policy which have gone radically and visibly wrong over the last half of the twentieth century in particular (unsustainable use of resources, waste of energy, pollution, declining service levels despite increasing investments, poor services to certain social and economic groups). During the best part of the century, it was assumed that adequate transport structures had to be built in order to provide an essential basis for growth and economic health. Accordingly, the main concern of transport planners and policy-makers was to "supply" transport services, and specifically to
ensure that the supporting infrastructure was adequate to support all projected requirements. The dominant approach was, therefore, to forecast and then build to satisfy demand. Likewise, in public transport planning, it was the supply and efficient operation of vehicles that were the main focus. According to some analysts, this focus on the supply side has led to unsustainable levels of traffic and resource utilisation.

The sustainable transport movement, which has gradually gained momentum over the last fifteen years, has gradually moved the emphasis of public spending and actions away from construction and supply to management and demand. In all cases, respect for the environment and prudent use of natural resources are taking centre stage.

Transport forecasts are also used to analyse transport patterns. Policy-makers are interested to know the situation with no policy in place and that in which their policy has been put in place. Forecasting is the process of estimating the number of vehicles, travellers or tonnes that will be using a specific mode of transport in the future. For example, a forecast estimates the number of vehicles on a planned road or bridge, trains on a railway line, passengers at an airport or ships calling on a seaport. Traffic forecasting starts with collecting data about existing traffic volumes. Together with data on population, employment, trip rates, travel costs, etc., traffic data are used to develop a traffic demand model. When data on future population, employment, etc. is fed into the model, this will produce an output for future traffic, typically estimated for each segment of the transport infrastructure, e.g. each road section or railway station. The figure below shows passenger transport forecasts for four background scenarios, and actual developments from 1970 until 2004.

![Figure 3-2: Development and forecast of passenger-kilometres (billions) in the Netherlands according to 4 scenarios](image)

Detailed traffic forecasts are used for several key purposes in transport policy, planning and engineering: to calculate infrastructure capacity, e.g. how many lanes should a bridge have; to
estimate the financial and social feasibility of projects, e.g. using cost-benefit analyses and social impact analyses; and to calculate the environmental impact, e.g. air and noise pollution.

The table provides an overview of the models dealing with strategic mobility by type of model (passenger/freight on the one side, and regional detail on the other). A total of 88 models in MDir deal with strategic mobility, most of them focusing on passenger transport at the national/regional level. Passenger models provide an urban and national/regional level of detail, with freight models focusing more on national/international detail.

**Table 3-4: Transport models for strategic mobility according to regional detail and passenger/freight**

<table>
<thead>
<tr>
<th></th>
<th>not known</th>
<th>urban/regional</th>
<th>Regional detail</th>
<th>national models/regional</th>
<th>national models incl. international</th>
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</thead>
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<td>17</td>
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<td>11</td>
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<tr>
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<td><strong>17</strong></td>
<td><strong>43</strong></td>
<td><strong>9</strong></td>
<td><strong>10</strong></td>
<td><strong>88</strong></td>
<td></td>
</tr>
</tbody>
</table>

3.1.2 Organisation

The following organisational issues are important when developing a transport model to assess strategic mobility:

- **Budget, planning, ambitions:** budgetary restraints are one of the factors determining the development of a model. A strategic mobility model ranges from a very simple forecasting method using aggregate figures to a very detailed regional model covering all modes of transport and covering both passenger and freight. A very detailed model covering passenger and freight at detailed regional level will cost about 1 to 2 million euros for a country, a straightforward regional model covering road traffic only can be built for about 100,000 euros. Of course, a detailed model will requires a large amount of planning. Some multimodal national models may take a few years to construct.

- **Project organisation:** strategic models usually involve the ministry of transport and/or the regional directorate of the ministry of transport. In addition, representatives from public transport companies (railway companies), stakeholders from the transport sector (shipper organisations, transport organisations) are also often involved.

- **Scope and type of model:** these are determined by the policy issues in hand; if there are specific recurring questions about detailed issues involving traffic on networks, a detailed network will have to be developed. If capacity issues on the network are to be addressed, a model covering both freight and passenger transport will need to be developed.

- **Choice of software/GIS:** nowadays all transport models are supported by a geographical information system (GIS). This allows the results of the model to be made better visible, for policy-makers and other parties. Another important issue is the choice of software,
Customers may already be using other software to run other parts of the model. This may determine the choice of software to used for the model.

- **Establish maintenance procedure**: once calibrated and validated, models can nowadays be used for about 2 to 5 years, after which updates will be necessary. This means that new data will be needed as input and for calibration and validation purposes. This aspect has to be considered when developing the model.

- **Tendering**: this is about who will construct the model. It is common practice to put the development of a strategic model out to tender. This requires drafting Terms of Reference in which the points mentioned above are covered (budget (including budget of civil servants) project organisation, scope and type of model, choice of software and maintenance). Usually 3 to 5 leading companies are invited to submit a proposal on the basis of the Terms of Reference.

The table below shows the models by mode of transport. Modes of transport include road transport (car, bus and lorry), rail transport (passenger and freight), inland waterways (abbreviated to iww) for freight, sea (maritime freight and ferry traffic), air (passenger and freight), slow modes (walking, cycling, mopeds). The majority of passenger transport models concentrate on road transport only. The other passenger models focus on multimodal aspects, covering rail and road transport and slow modes (for regional applications) for transport by ferry and air if the model is designed for long-distance transport. Freight models in general cover more than one mode.

| Table 3-5: Transport models for strategic mobility by mode of transport and passenger/freight |
|-----------------------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| modes                                        | not known | passenger | freight | both |
| Road                                         | 0         | 23        | 2       | 2    | 27 |
| sea/ferry                                   | 0         | 0         | 1       | 0    | 1  |
| road/rail                                   | 0         | 7         | 3       | 2    | 12 |
| road/air                                    | 0         | 0         | 2       | 0    | 2  |
| road/rail/iww                               | 0         | 0         | 4       | 2    | 6  |
| road/rail/sea                               | 0         | 0         | 2       | 0    | 2  |
| road/rail/air                               | 0         | 4         | 0       | 0    | 4  |
| road/rail/Slow                              | 0         | 8         | 0       | 1    | 9  |
| road/rail/iww/sea                           | 0         | 0         | 3       | 2    | 5  |
| road/rail/sea/air                           | 0         | 2         | 0       | 0    | 2  |
| road/rail/iww/sea/air                       | 0         | 1         | 0       | 2    | 3  |
| **Total**                                   | **13**    | **47**    | **17**  | **11** | **88** |

### 3.1.3 Model development

Traffic forecasts start with making a forecast for the key variables that are input in transport models. Examples include the number of residents, number of households, gross domestic product, car ownership, and the location choices of individuals and businesses. This should be done for a number of scenarios that differ for instance on the level of international
cooperation and level of privatisation. Table 3-6 shows some of the key variables for four future scenarios for the Netherlands. Regional infrastructural plans are also a key input for strategic models.

Table 3-6: Key mobility figures in the Netherlands under four scenarios (input for demand models).

<table>
<thead>
<tr>
<th></th>
<th>Global Economy</th>
<th>Strong Europe</th>
<th>Transatlantic Market</th>
<th>Regional Communities</th>
<th>Unit of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhabitants in 2040</td>
<td>19.7</td>
<td>18.9</td>
<td>17.1</td>
<td>15.8</td>
<td>Million</td>
</tr>
<tr>
<td>GDP/head 2040</td>
<td>221</td>
<td>156</td>
<td>195</td>
<td>133</td>
<td>2001=100</td>
</tr>
<tr>
<td>Households</td>
<td>10</td>
<td>8.6</td>
<td>8.5</td>
<td>6.9</td>
<td>Million</td>
</tr>
<tr>
<td>Passenger car ownership</td>
<td>11.8</td>
<td>9.7</td>
<td>9.5</td>
<td>7.7</td>
<td>Million</td>
</tr>
</tbody>
</table>

(Source: www.welvaartenleefomgeving.nl)

**Extensive method**

In addition to other inputs, the key variables mentioned above are input in demand and assignment models. Based on these key input variables, the demand models and assignment models determine how many passenger and freight trips will be made between each region by each mode. For freight transport, the use of distribution centres and terminals is also determined, because they increase the number of tonnes lifted and influence the number of vehicle kilometres travelled. The assignment models ultimately determine how the available infrastructure is used. The interaction between the use of infrastructure and the number of trips made by each mode and between each combination of regions should be kept in mind. If there is a lot of congestion on a certain route or in a certain region, people or carriers may choose other modes of transport or indeed other destinations. Conversely, the more people choose to travel a certain route by a certain mode, the more congested that route will become. Finally, impact models can be used to determine, for instance, the level of NOx emissions. The results of this process for the four scenarios in the Netherlands are shown in Table 3-7.

Table 3-7: Key mobility figures in the Netherlands under four scenarios (output of demand, assignment and impact models).

<table>
<thead>
<tr>
<th></th>
<th>Global Economy</th>
<th>Strong Europe</th>
<th>Transatlantic Market</th>
<th>Regional Communities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger kilometres</td>
<td>+40</td>
<td>+30</td>
<td>+20</td>
<td>+5</td>
</tr>
<tr>
<td>Freight transport tonne-km</td>
<td>+120</td>
<td>+40</td>
<td>+65</td>
<td>-5</td>
</tr>
<tr>
<td>Congestion hours</td>
<td>+70</td>
<td>0</td>
<td>-10</td>
<td>-70</td>
</tr>
<tr>
<td>NOx emissions</td>
<td>-40</td>
<td>-70</td>
<td>-55</td>
<td>-75</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>+70</td>
<td>+20</td>
<td>+35</td>
<td>-5</td>
</tr>
</tbody>
</table>

(Source: www.welvaartenleefomgeving.nl)

**Simple method**

If the resources necessary to construct or use extensive transports models are not available, another solution would be to use time series analyses. Time series analysis is less accurate, because it assumes that future developments can be predicted on the basis of past developments and does not include many interactions in terms of, for instance, congestion levels and levels of demand.
Table 3-8 shows all models from MDir that can be used for strategic modelling. A few some best practice examples of models that can be used for strategic modelling are presented below:

- **Freight**
  - SMILE (see section 13.1.2 of part 3 and section 3.2 of part 4): this model can be used to carry out freight demand forecasts. It determines freight transport flows within certain regions in the Netherlands and in relation to the Netherlands as a whole for different modes of transport. Logistics operations like transhipment at distribution centres are also modelled. This model has been used to develop the four future scenarios described above.
  - The logistics module of TRANS-TOOLS (see section 13.1.1 of part 3 and section 3.1 of part 4): this module is part of the TRANS-TOOLS model. It determine for each transport chain whether or not transhipment takes place and, if so, in which region in Europe (NUTS2 level) the distribution activities take place. This is important for making forecasts because distribution activities increase the number of tonnes lifted in certain regions.

- **Passenger demand**
  - MEPLAN and TRANUS (see section 13.2.1 of part 3 and section 4.1 of part 4): these models are land use/transport models (LUTI). LUTI models are developed mainly for multi-purpose strategic use. They are used to analyze the mutual relationships between location and transportation processes.
  - SAMPERS (see section 13.2.2 of part 3 and section 4.2 of part 4): this is the national/regional Swedish passenger transport forecasting system. It can be used in a strategic planning context to model the impact on demand of new infrastructure, changes in income, population and employment, impact assessments and assessments of pricing and regulatory policies.
  - A trip-based transport model from the Pilsen region (see section 13.2.3 of part 3 and section 4.3 of part 4): this model was developed to test the impact of different policy measures on future transport supply and demand in the Pilsen region.

- **Linked models:**
  - TRANS-TOOLS (see section 13.6.1 of part 3 and section 8.1 of part 4): TRANS-TOOLS is a model at European level. It combines an economic model, passenger model and transport model and can be used to provide forecasts of both passenger and freight transport.
<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM-7</td>
<td>NK</td>
<td>Netherlands</td>
<td>NRM Groeimodel</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>EUNET MEPLAN</td>
<td>NK</td>
<td>not known</td>
<td>Mobiliteitsverkenner (MOVE)</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>NATRA</td>
<td>NK</td>
<td>not known</td>
<td>SRE-model</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Route Choice Model for International Trade</td>
<td>NK</td>
<td>not known</td>
<td>RVMK-Rotterdam (Stadsregio Rotterdam)</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>SKEPRO</td>
<td>NK</td>
<td>not known</td>
<td>GGA-’s-Hertogenboch</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>ATIS- Transalpine pilot study and demonstrator, D10 MESUDEMO</td>
<td>NK</td>
<td>not known</td>
<td>BRU- model (Bestuur regio Utrecht)</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Inland freight transport: An intermodal model for Switzerland</td>
<td>NK</td>
<td>not known</td>
<td>Haarlem-Haarlemmermeer</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>The National Transport Model (LTM)</td>
<td>NK</td>
<td>not known</td>
<td>Genmod - Dienst IVV Amsterdam</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Stockholm Model System</td>
<td>NK</td>
<td>Sweden</td>
<td>Model &quot;Bereikbaarheidskaart&quot; Nederland</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Ten Corridors of Helsinki freight and passenger database (PHARE)</td>
<td>I</td>
<td>Eastern Europe</td>
<td>model Stedendriehoek (Apeldoorn, Zutphen, Deventer)</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>NEAC</td>
<td>I</td>
<td>EC</td>
<td>Model Arnhem Nijmegen</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>STEEDS</td>
<td>I</td>
<td>EC</td>
<td>Model Regio Twente</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>TRANS-TOOLS</td>
<td>I</td>
<td>EC</td>
<td>GGA-Midden Brabant</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>SIMTRANS</td>
<td>I</td>
<td>France</td>
<td>GGA-Breda</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>MAP-1</td>
<td>I</td>
<td>France</td>
<td>Model Regio Alkmaar</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>HGV model</td>
<td>I</td>
<td>Germany</td>
<td>Model Regio Groningen- Assen</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>STREAMS</td>
<td>I</td>
<td>Western Europe</td>
<td>Model Holland Rijnland (Leiden)</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>OD Estim</td>
<td>I</td>
<td>Western Europe</td>
<td>Model Haaglanden (The Hague)</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>EUFRANET</td>
<td>I</td>
<td>Western Europe</td>
<td>National Passenger Transportation Model</td>
<td>N \ R</td>
<td>Norway</td>
</tr>
<tr>
<td>EVOTRANS (Belgium)</td>
<td>N \ I</td>
<td>Belgium</td>
<td>The Climate Model</td>
<td>N \ R</td>
<td>Norway</td>
</tr>
<tr>
<td>GPVTI</td>
<td>N \ I</td>
<td>Finland</td>
<td>GODMOD</td>
<td>N \ R</td>
<td>Norway</td>
</tr>
<tr>
<td>GVF -modell</td>
<td>N \ I</td>
<td>Finland</td>
<td>Transport model for Poland</td>
<td>N \ R</td>
<td>Norway</td>
</tr>
<tr>
<td>SIMU-GV</td>
<td>N \ I</td>
<td>Germany</td>
<td>Model for transport in Norwegian foreign trade</td>
<td>N \ R</td>
<td>Norway</td>
</tr>
<tr>
<td>Fehmarn Belt Freight Model</td>
<td>N \ I</td>
<td>Germany</td>
<td>NMTS</td>
<td>N \ R</td>
<td>Norway</td>
</tr>
<tr>
<td>VM-PFV</td>
<td>N \ I</td>
<td>Germany</td>
<td>Transport Model for Poland</td>
<td>N \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>ASTRITA-Italia</td>
<td>N \ I</td>
<td>Italy</td>
<td>ASZCZ</td>
<td>N \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>ILiM model</td>
<td>N \ I</td>
<td>Poland</td>
<td>SAMPERS</td>
<td>N \ R</td>
<td>Sweden</td>
</tr>
<tr>
<td>Lincost</td>
<td>N \ I</td>
<td>UK</td>
<td>Traffic Model for Antwerp (freight module)</td>
<td>U \ R</td>
<td>Belgium</td>
</tr>
</tbody>
</table>
Strategic forecasts for freight and passenger by Flemish Authority

Freight Transport (Czech Republic) N \ R Czech Rep

Danish road traffic model N \ R Denmark

Evaluation model applied to the Greek operational programme “Railways 1994-1999”

SAMI N \ R France

SPADIS N \ R France

Strategic freight forecasting model for Germany N \ R Germany

Prometeia N \ R Italy

The Netherlands National Model System (LMS) N \ R Netherlands

New Regional Model (NRM) N \ R Netherlands

SMART 2.0 N \ R Netherlands

MOBILEC N \ R Netherlands

LMS N \ R Netherlands

TEM II N \ R Netherlands

(AIDA U \ R Denmark

Passenger Transport Model for Tempere Metropolitan Area U \ R Finland

Modele Strategique de Deplacements de Fagglomeration Lyonnaise U \ R France

RES-DYANM U \ R France

MODUS U \ R France

FRETURB U \ R France

MARS U \ R France

HPTS U \ R France

Hungarian models developed by ProUrbe Ltd devveloped in own Sofware or EMME/2 U \ R Hungary

ETRAFOM U \ R Italy

PW Prognos U \ R Poland

FREDRIK U \ R Sweden

SERTM U \ R UK

Central Scotland Transport Model (CSTM) U \ R UK

Greater Manchester Area Transport Study (GMATS) U \ R UK

Trans-Pennine Traffic Study U \ R UK

(NK not known, I = international, N = national, R = regional, U = urban)

Pitfalls

Making a forecast is a complex task because it looks at the future and the future is by definition uncertain. By carefully choosing the scenarios, this risk can partially be overcome. Major changes in exogenous variables (for instance, transport in relation to China) form another potential risk, because models are usually not suited to dealing with major shocks in input variables. This is especially relevant to strategic modelling because of the fact that forecasts are usually long-term. Major changes are more likely to occur in the long term than in the short term. If major shocks are input in the model, the results should always be interpreted with great care.

3.2 Demand Analysis

3.2.1 Policy needs

In line with standard micro economic theory, transport systems can be explained on the basis of the supply and demand theory, as is valid for industries, commodities, etc. The existence of network effects and choices between different modes, dissimilar goods, i.e. car and bus travel,
make it difficult to estimate transport demand. Models designed to estimate the likely choices between dissimilar goods involved in transport decisions are called discrete choice models.

Demand can be measured as numbers of journeys made or total distance travelled across all journeys, i.e. passenger-kilometres for public transport or vehicle-kilometres for private transport or tonne-kilometres for freight transport. Origin-destination matrices for freight and passenger transport, providing the number of passengers and/or freight between the regions of origin and destination, are also commonly used to measure demand. Supply is considered to be a measure of capacity. The price (of travel) is measured using the generalised cost of travel, which includes both money and time expenditure.

The effect of an increase in supply, i.e. an increase in capacity, is relevant to transport analysis as this brings about induced demand. It may also bring about environmental consequences, which are usually significant. In addition to providing benefits to their users, transport networks impose positive as well as negative externalities on non-users. Including these externalities in the analysis should be a part of any transport policy analysis.

Positive externalities of transport networks may include the ability to provide emergency services, increases in land value and agglomeration benefits. Negative externalities are wide-ranging and may include local air pollution, noise pollution, light pollution, safety hazards, community severance, and congestion. The contribution of transport systems to potentially hazardous climate change is a significant negative externality, one which is difficult to assess in quantitative terms and, hence, difficult (but not impossible) to include in transport economics-based research and analysis.

Traffic congestion is a negative externality imposed by road users on other road users or potential road users. Within the transport economics community, road pricing is considered to be an appropriate mechanism to deal with this problem (i.e. to internalise the externality) by allocating scarce roadway capacity to users. Capacity expansion is also a potential mechanism to address traffic congestion, but is often undesirable (particularly in urban areas) and sometimes has questionable benefits in terms of induced demand. Congestion is not limited to road networks; the negative externality imposed by congestion also plays a role in busy public transport networks and crowded pedestrian areas.

Transport network effects occur when more travellers are better connected to a network, i.e. in case of an extension or improvement. These effects are complex and multi-dimensional, firstly because of the large number of relationships and responses occurring when the transport system is improved. Secondly, transport is a network, both in the sense that there is a physical transport network, and in the sense that, while transport is an intermediate good, it is related to the final production, consumption and factor markets which it serves. In addition to direct network effects which are reflected in trip rates, destination choice, route choice and so on, there are also indirect network effects. Transport network improvements will change the accessibility of the local or regional economy and also, one would expect, land use, production and labour market patterns. Households and businesses will wish to relocate in order to take advantage of the new opportunities and these changes will be facilitated by the property development sector. New residential, commercial or industrial developments may occur. This is, in turn, likely to lead to new commuting and physical distribution patterns,
changes in the competitiveness of businesses and, in particular locations, and so local economic competitiveness may change. These may be the indirect effects of a transport initiative on the rest of the economic system. These effects on land use, migration and the local economy will in turn have a knock-on effect on the transport system. A spatial redistribution of activities (production, work, home) will again lead to a different pattern of transport choice-making. These knock-on effects are called indirect transport network effects.

The table below shows the models that address demand analysis by regional detail, and the scope of the models. The majority of models has been designed for freight transport issues. Contrary to other policy areas, freight models have also been developed for urban use to address this issue.

Table 3-9: Transport models for demand analysis by regional detail and passenger/freight

<table>
<thead>
<tr>
<th>Regional detail</th>
<th>Passenger not / freight known</th>
<th>Passenger not / freight unknown</th>
<th>Urban / regional</th>
<th>National models / regional</th>
<th>National models incl. international</th>
<th>International models</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Freight</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Both</td>
<td>0</td>
<td>6</td>
<td>10</td>
<td>9</td>
<td>4</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

3.2.2 Organisation

Short description of the relationship between passenger demand and infrastructure planning.

- **Budget, planning, ambitions:** direct effects are comparable to strategic models as described in section 3.1. The difficulty is the demand that arises from the indirect network effects. In this case, one needs a model that describes the effect of changes in accessibility on the economic circumstances. This is usually incorporated into spatial computable general equilibrium models, known as SCGE models; i.e. the change due to a change in accessibility will change the economic circumstances of the region (the market area becomes larger, the supply of labour becomes larger). Both the transport model and the SCGE model interact (see figure below) in order to capture direct and indirect network effects.

- **Project organisation:** due to the inclusion of indirect network effects, economic specialists need to be included in the study team as well as the steering group.

- **Scope and type of model:** preferably the SCGE model should be of the same geographical scale as the transport model. It should be noted that, from an economic perspective, most SCGE models are partial in the sense that revenue raising in case of taxation or spending in case of investment will be of no consequence. In some cases, the impact on government budgets is studied, but this field still needs to be developed on a regional scale.

- **Choice of software/GIS:** SCGE models, in particular, show the economic consequences of transport policy measures clearly in terms of changes in regional GDP due to the policies. They also provide a response to the change in cohesion within the study areas (do rich regions become richer and poor ones become poorer) as a result of the policy.
Establish maintenance procedure: economic SCGE models must be updated once every few years as they are calibrated mostly on the basis of existing data, generating model parameters that are used in the future as well.

Tendering: the tendering procedure is not really different from strategic models, except that fewer consultancies will usually focus on the indirect effects and only one consortium consisting of “attractive” parties will usually be able to carry out the study. In order to prevent resources from being wasted, a prior selection of consortia may be made to see who can meet criteria for handling these complex activities.

As shown in the table below, nearly all models cover multimodal aspects, which is in line with demand analysis. It should be noted that all models cover direct effects. None of the models, except the TRANS-TOOLS models, are able to capture any indirect effects.

**Table 3-10: Transport models for demand analysis by mode of transport and passenger/freight**

<table>
<thead>
<tr>
<th>modes</th>
<th>not known</th>
<th>Passenger</th>
<th>Freight</th>
<th>both</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/iww</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/sea</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/air</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/slow</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/iww/sea</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/iww/slow</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/sea/air</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/iww/sea/air</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1</td>
<td>5</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

**3.2.3 Model development**

The modelling of demand is also an important issue in addition to modelling direct network effects, such as modal split and trip generation. These are also covered by other questions related to other policy areas (such as strategic mobility). The description of the models given in this section focuses on key issues associated with transport network effects identified in previous sections. The key issues are:

- Whether the model includes a network;
- Whether it contains supply, on the one hand, and demand side responses, on the other, if supply/demand interactions are included; and
- Whether it includes direct and/or indirect transport network effects, and economic network effects (changes to other sectors of the economy triggered by the transport initiative/project/policy).
The table below provides an overview for the models included in the IASON study. The models studied in IASON\(^6\) cover a broad range of types. Some of the models can be labelled as pure transport models: SCENES, NEAC, VACLAV. There is an SCGE (spatial computable general equilibrium) model, CGEurope (see section 13.3.1 of part 3 and section 5.1 of part 4), that uses transport model input and produces changes in economic (monetary) flows (of different sectors) between regions. There is a recursive simulation model of the socio-economic development of regions, known as the SASI model. This model uses exogenous assumptions about economic and demographic developments. Finally, the models include a system dynamic model, ASTRA. This type of model is not an equilibrium model and, unlike the other models, it works at an aggregate level. Whereas the other models operate at a regional level (NUTS II/III), ASTRA works at a national level. There is, however, a link between ASTRA and VACLAV so that the model can be applied at lower levels of aggregation.

One distinctive feature of the models listed below is that none of them are truly capable of dealing with supply side responses associated with economies of scale, scope and density. Traditionally, congestion effects are included in most transport models (e.g. SCENES, NEAC, VACLAV), although they are not very well represented in European-wide models due to the absence of short-distance traffic from the models. In the other models (SASI, CGEurope, and ASTRA), congestion is entered exogenously. However, these models do not provide for demand/supply iteration within the transport system, meaning that changes in congestion effects arising from changes in other sectors of the economy will not be represented.

Pure transport models (SCENES, NEAC, VACLAV) capture direct transport network effects, but do not include indirect transport network effects. Within VACLAV the total number of trips can change (unlike in the other models) and, accordingly, indirect transport network effects are embedded in an approximate manner. NEAC also incorporates indirect transport network effects if used in combination with a routine developed in the Netherlands. ASTRA includes a representation of direct and indirect transport network effects, however, the model structure does not allow these effects to be identified separately.

SASI, ASTRA and CGEurope include economic network effects, i.e. any changes in other sectors of the economy in terms of employment, sectoral GDP, etc, resulting from a transport initiative. Indirect transport network effects (changes in travel times, volumes on links, etc.) cannot, however, modelled in SASI or CGEurope. This is because there is no feedback routine between them and the transport models from which transport costs are derived. In the new TRANS-TOOLS model, the link between indirect effects and their representation in the network is explicitly included.

---

Figure 3-3: Iterative use of spatial general equilibrium models and transport network models to estimate indirect transport network effects.
Table 3-11: European models suitable for demand analysis, including direct and indirect network effect studied in IASON

<table>
<thead>
<tr>
<th>Model type</th>
<th>SCENES</th>
<th>NEAC</th>
<th>VACLAV</th>
<th>SASI</th>
<th>CGEurope</th>
<th>ASTRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>European transport model, freight and passenger transport</td>
<td>European transport model, freight transport</td>
<td>European transport model, passenger only, used in conjunction with NEAC</td>
<td>European model: SASI explains locational structures and change by including infra in a production function</td>
<td>SCGE, European model</td>
<td>System dynamics model used in conjunction with VACLAV, not an equilibrium model</td>
<td></td>
</tr>
<tr>
<td>Network included</td>
<td>Yes, multi-modal network</td>
<td>Yes, multi-modal network</td>
<td>Yes, multi-modal network</td>
<td>Yes, but not for traffic assignment</td>
<td>schematic network on OD level obtained from SASI, not for assignment</td>
<td>schematic network not for assignment, in combination with VACLAV a more detailed model is obtained</td>
</tr>
<tr>
<td>Supply side responses</td>
<td>No economies of scale, scope, density included</td>
<td>No economies of scale, scope, density included</td>
<td>No economies of scale, scope, density included</td>
<td>No economies of scale, scope, density included</td>
<td>No feedback making costs dependent on flows, neither due to congestion nor due to economies of scale, density</td>
<td>Changes in the supply side enter via the capacity model via a markup</td>
</tr>
<tr>
<td>Demand side responses</td>
<td>Generative effect in principle not included, a fixed matrix for passenger and for freight a redistributional effect</td>
<td>Generative effect not included, model estimated on short run time series</td>
<td>Yes, changes in transport infrastructure have impacts on the time costs, which has an effect on generation and distribution of trips</td>
<td>No generative effect, distributive effect is analysed</td>
<td>Generative effect included, but no feedback with transport model</td>
<td>Yes, generation included though several processes</td>
</tr>
<tr>
<td>Demand/Supply Interaction</td>
<td>Congestion modelling included for road</td>
<td>Congestion modelling included for road (in combination with VACLAV)</td>
<td>Congestion modelling included for road freight and passenger interaction in combination with NEAC</td>
<td>Congestion appears as disutility and is obtained exogenously</td>
<td>Congestion appears as disutility and is obtained exogenously</td>
<td>Yes, but only rough capacity models</td>
</tr>
<tr>
<td>Direct transport network effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes in combination with VACLAV</td>
</tr>
<tr>
<td>Indirect transport network effects</td>
<td>In principle not, although a redistributional effect for freight</td>
<td>Possibly, in combination with a ECONEAC</td>
<td>Possibly, because a generative effect is included</td>
<td>No</td>
<td>No</td>
<td>Yes in combination with VACLAV</td>
</tr>
<tr>
<td>Economic network effects</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Table 3-12: List of models from MDir that can be used for demand analysis

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMILE</td>
<td>N \ R</td>
<td>Netherlands</td>
<td>Quinquin Fret</td>
<td>N \ R</td>
<td>France</td>
</tr>
<tr>
<td>SIMPT</td>
<td>N \ R</td>
<td>Italy</td>
<td>Combined Transport Model</td>
<td>N \ I</td>
<td>Greece</td>
</tr>
<tr>
<td>MDS Transmodal Trade Forecasting model</td>
<td>N \ I</td>
<td>UK</td>
<td>Trans European North South Motorway Corridor</td>
<td>N \ I</td>
<td>Western Europe Partly</td>
</tr>
<tr>
<td>MATISSE-INTRAPLAN TRAFFIC AND PROFITABILITY FOR A WESTERN EUROPEAN HIGH SPEED TRAIN NETWORK MODEL</td>
<td>I</td>
<td>France</td>
<td>Prognos Goods Transport Forecast Model</td>
<td>N \ I</td>
<td>Switzerland</td>
</tr>
<tr>
<td>NRM Groeimodel</td>
<td>N \ R</td>
<td>Netherlands</td>
<td>E3ME</td>
<td>N \ I</td>
<td>UK</td>
</tr>
<tr>
<td>Ten Corridors of Helsinki freight and passenger database (PHARE)</td>
<td>I</td>
<td>Eastern Europe</td>
<td>Short sea shipping model</td>
<td>N \ I</td>
<td>UK</td>
</tr>
<tr>
<td>Strategic freight forecasting model for Germany</td>
<td>N \ R</td>
<td>Germany</td>
<td>Distribution coast model</td>
<td>N \ I</td>
<td>UK</td>
</tr>
<tr>
<td>IVV / Nordrhein-Westfalen freight model</td>
<td>U \ R</td>
<td>Germany</td>
<td>NEMO</td>
<td>N \ I</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Baden-Wurttemberg Freight Transport Model</td>
<td>U \ R</td>
<td>Germany</td>
<td>SISD</td>
<td>N \ R</td>
<td>Italy</td>
</tr>
<tr>
<td>Hamburg freight model</td>
<td>U \ R</td>
<td>Germany</td>
<td>SCENES 10-11-12 Model System</td>
<td>I</td>
<td>EC</td>
</tr>
<tr>
<td>OEST France (passenger/freight models)</td>
<td>N \ R</td>
<td>France</td>
<td>SIMTRANS</td>
<td>I</td>
<td>France</td>
</tr>
<tr>
<td>Austrian passenger/freight models</td>
<td>N \ R</td>
<td>Austria</td>
<td>VISEM (under Windows)</td>
<td>U \ R</td>
<td>France</td>
</tr>
<tr>
<td>LASER</td>
<td>NK</td>
<td>not known</td>
<td>VISUM 7.0</td>
<td>U \ R</td>
<td>France</td>
</tr>
<tr>
<td>COMBI FEEDER MODEL</td>
<td>N \ I</td>
<td>Denmark</td>
<td>HELVI</td>
<td>N \ R</td>
<td>Finland</td>
</tr>
<tr>
<td>STAN (Finland)</td>
<td>N \ R</td>
<td>Finland</td>
<td>TRAM</td>
<td>U \ R</td>
<td>Norway</td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

3.3 Land use planning

3.3.1 Policy needs
Regional or local development is often identified as the main objective of new infrastructure. There are many direct and indirect relations between changes in the infrastructure and the impact on land use planning. Improved accessibility can increase growth in an area and lead to relocations of homes and businesses. Changes in the use of an area (e.g. industrial development area) will influence demand for passenger transport as well as freight transport. The links are obvious, but the real question is to what extent the transport sector and land use will be affected, and whether information can be obtained about any unforeseen consequences. Accessibility is the main driver and link between the infrastructure and land use. The value of land will increase if it is linked to major infrastructure. It is of political
interest to obtain information on how new development areas can help finance, for example, new or additional infrastructure. There are several examples of this; the new Orestad region in Copenhagen, where the revenues from selling land for offices and flats were used to finance the metro extension and regional train services. The congestion charge to be introduced in Edinburgh is also intended to be used for infrastructure improvements, which is another way of associating land use developments with tax effects and transport effects. Major developments of new harbours are examples of investments which contain infrastructure investments and at the same time require extensive land use planning.

Figure 3-4: The ‘land use transport feedback cycle’

The major theoretical approaches to explaining the two-way interaction between land use and transport in metropolitan areas include technical theories (urban mobility systems), economic theories (cities as markets), and social theories (society and urban space):

- **Impact of land use on transport.** The impact of high residential density on reducing average trip length is likely to be minimal in the absence of travel cost increases, whereas high-density employment has a positively effect on average trip length. Attractive neighbourhood facilities are a ‘pull’ factor for reducing trip length. Since peripheral locations usually produced longer trips, trip length is likely to be adversely affected by city size. With regard to trip frequency, little or no impact is to be expected from land use policies according to the theory of travel budgets. Residential and employment density, as well as large agglomeration size and good public transport accessibility, tend to have a positive impact on the use of public transport, while neighbourhood design and a mix of homes and businesses and shorter commuter journeys are likely to increase the shares accounted for by cycling and walking.

- **Impact of transport on land use.** The impact of transport on land use will partly depend on any changes in the accessibility of a location. Higher accessibility will increase the attractiveness of a location for all types of land use, thus influencing the direction of new
urban development. If, however, accessibility increases across a city, this will lead to a more dispersed settlement structure.

- **Impact of transport on transport.** This impact is included because it tends to be much stronger than the impact of land use on transport and of transport on land use. While travel cost and travel time have a negative impact on both trip length and trip frequency, accessibility has a positive impact on trip length and frequency. Mode choice will depend on the relative attractiveness of a mode compared to all other modes. The fastest and cheapest mode is likely to have the highest modal share.

In general, theoretical considerations support the conclusion that the impact of 'pull' measures, e.g. land use measures or improvements in public transport, is much weaker than the impact of 'push' measures, i.e. increases in travel time or travel cost or other mobility constraints.

<table>
<thead>
<tr>
<th>Table 3-13: Transport models with regional and or land use details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional detail</td>
</tr>
<tr>
<td>Passenger /freight not known</td>
</tr>
<tr>
<td>passenger</td>
</tr>
<tr>
<td>freight</td>
</tr>
<tr>
<td>both</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

### 3.3.2 Organisation

The following organisational issues are important when developing a transport model that links the impact of transport and land use. There are generally many issues that are similar to those related to strategic mobility as mentioned in Section 3.1.2.

- **Budget, planning, ambitions:** the budget is one of the determining factors in developing a model. A land use interaction model is a large complex model, the development of which will require a substantial budget and resources. It will often be more feasible to use existing transport models and land use models and available resources to develop links between the models. This will, however, also requires considerable resources because these models have not been developed with any linking to other models in mind. The required level of detail from simple linkages to very sophisticated models obviously determines the resources needed.

- **Project organisation:** land use/transport models will usually involve the ministry of transport and/or the regional directorate of the ministry of transport. In addition, representatives from public transport companies (railway companies), stakeholders from the freight sector (shippers organisations, transport organisations), and stakeholders responsible for physical planning, are often involved.
• **Scope and type of model:** these are determined by the policy issues in hand; if there is a focus on regional economies, then the SCGE model will be appropriate; if the focus is on the demand for development land, a model will have to be used specifying the accessibility requirements for passengers and/or freight transport and infrastructure, typically a LUTI-style model.

• **Choice of software/GIS:** these days all transport models are supported by a geographical information system (GIS). This allows the results of the model to be made better visible, for policy-makers as well. GIS software often supports data storage and transferability options that are valuable for model development. GIS is also extensively used in physical planning and land use modelling. The choice of software is also an important issue. Customers may already have other software in place to run other parts of the model. This may determine the software that can be used for the model.

• **Establish maintenance procedure:** once calibrated and validated, models can nowadays be used for about 2 to 5 years, after which updates will be necessary. This means that new data will be needed for model input, calibration and validation. This aspect has to be considered when developing the model.

• **Tendering:** The last issue is about who will construct the model. This is not very different from strategic models. It is common practice to put the development of a strategic model out to tender. This means that one first has to describe the Terms of Reference covering the previous points (budget (including budget of civil servants), project organisation, scope and type of model, choice of software and maintenance). Usually 3 to 5 leading companies are invited to submit a tender on the basis of the Terms of Reference.

Land use and spatial activity models mainly focus on passenger transport. More than 80% of models contained in the MDir model directory focus on the links between passenger transport and regional impact. This is because much of the interest has been on urban development, where labour supply and demand is more important than interurban transport demand. The focus has changed over the last few years, but has still not been implemented in model developments, with the exception of TRANS-TOOLS covering both passenger and freight transport and links with the economy. For traditional LUTI models, this is something which still requires developing.

**Table 3-14: Transport models with regional and or land use details and the scope of the models**

<table>
<thead>
<tr>
<th>modes</th>
<th>passenger/freight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
<td>passenger</td>
</tr>
<tr>
<td>road</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/sea</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/slow</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>21</td>
</tr>
</tbody>
</table>
3.3.3 Model development

Models that link land use to transport are rather large complex models. The modelling of the crucial linkages can be complex and the level of detail can be quite large. The complexity of the transport model and land use model involved is also relatively high. The overall complexity of the model is therefore substantial and any development of the model will have to start by recognising the key interest.

1. Identify scope of model
2. Find relevant transport model
3. Find relevant land use model
4. Define relevant input and output variables from the two models
5. Develop model linkages
6. Calibration

An added problem is that it is difficult to investigate the impact and find relevant data to calibrate the model to reflect the actual situation in terms of both traffic and land use.

There are a number of different model approaches and applied models (27) as shown in Table 3-13. Models with a spatial distribution are used to emphasise certain of the land use issues that are relevant, especially with respect to the linkage between transport and economic development where, for example, SCGE models are informative. These models link transport demand to specific regions and link the impact on transport costs between regions to changes in economic activity in different regions.

SCGE models do not emphasise the physical side of the spatial distribution of demand and economic activity. This requires another model approach, which is also the one to be considered for land use. A typical model approach would be LUTI (Land use-Transport-Interaction) models, which link transport models to explicit land use models.

A typical land use model system contains four elements:
1. a transport model (passenger and/or freight)
2. an economic model
3. an (urban) land use model
4. a migration model

The migration model is included to be able to investigate changes occurring if location of households change either through time or in a static comparative way due to exogenously introduced policy changes etc.

**Linkage between sub-models**

Each of the sub-models included is developed independently (possibly for other purposes prior to the LUTI model development). The important activity is to link the model to the system approach. An illustration of a LUTI model used for Edinburgh (Simmonds et al, 2005), which also focuses on economic impact, is shown in Figure 3-5.

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Table 3-15 presents all models from MDir that can be used for land use, regional and transport modelling. Best practice examples of models that can be used for land use/regional-transport modelling are presented below:

- MEPLAN and TRANUS (see section 13.2.1 of part 3 and section 4.1 of part 4): these models are land use/transport models (LUTI). LUTI models are developed mainly for multi-purpose strategic use. They are used to analyse the mutual relationships between location and transportation processes.

- SAMPERS (see section 13.2.2 of part 3 and section 4.2 of part 4): this is the national/regional Swedish passenger transport forecasting system. It can be used in a strategic planning context to model the demand effects of new infrastructure, changes in income, population and employment, impact assessments and assessments of pricing and regulation policies.

- TRANS-TOOLS (see section 13.6.1 of part 3 and section 8.1 of part 4): TRANS-TOOLS is a model on the European level. It combines an economic model, passenger model and transport model and can be used to make forecasts for both passenger and freight transport.
Table 3-15 List of models from MDir that can be used for land use planning

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVV-NRWF</td>
<td>N \ R</td>
<td>Germany</td>
<td>ITLUP</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>WOLOCAS-II</td>
<td>U \ R</td>
<td>Netherlands</td>
<td>KIM</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>Spatial Development and Public Transport (ROOV)</td>
<td>U \ R</td>
<td>Netherlands</td>
<td>LILT</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>TIGRIS (Transport Infrastructure Landuse Interaction Simulation)</td>
<td>U \ R</td>
<td>Netherlands</td>
<td>METROSIM</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>LASER</td>
<td>NK not known</td>
<td></td>
<td>MUSSA</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>SUPERNOVA</td>
<td>U \ R</td>
<td>France</td>
<td>POLIS</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>West Midlands Strategic Transport Model (WMSTM)</td>
<td>U \ R</td>
<td>France</td>
<td>RURBAN</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>IMREL</td>
<td>U \ R</td>
<td>Sweden</td>
<td>STASA</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>TILT</td>
<td>NK not known</td>
<td></td>
<td>TRANUS</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>SYNERGETIC</td>
<td>NK not known</td>
<td></td>
<td>URBANSIM</td>
<td>U \ R</td>
<td>not known</td>
</tr>
<tr>
<td>BOYCE</td>
<td>U \ R not known</td>
<td></td>
<td>PETS D10 Transalpine Freight Case Study</td>
<td>I Western Europe Partly</td>
<td></td>
</tr>
<tr>
<td>DELTA/START</td>
<td>U \ R not known</td>
<td></td>
<td>CUFM</td>
<td>NK not known</td>
<td></td>
</tr>
<tr>
<td>HUDS</td>
<td>U \ R not known</td>
<td></td>
<td>BROBISSE</td>
<td>NK Denmark</td>
<td></td>
</tr>
<tr>
<td>IRPUD</td>
<td>U \ R not known</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

3.3.4 Model examples

The following classification of several model examples has been taken from work on land use models carried out by SACTRA in the UK.9

**STATIC MODELS: DSCMOD, IMREL AND MUSSA**

Static models in use today are typically developed for two reasons:

- as a means of adding a land use impact dimension to existing transport models, without embarking on the extra work needed to create a dynamic model; and/or
- because the static model represents an equilibrium state which is of interest in itself.

The category of static models can be divided into:

- models which estimate the pattern of land use given one set of transport inputs; and
- models which estimate changes in land use given two sets of transport inputs.

---

8 ‘Not known’ also means that these models are generic, so that they can be applied in different regions.

9 David Simmonds Consultancy in collaboration with Marcial Echenique and Partners Limited. REVIEW OF LAND USE/TRANSPORT INTERACTION MODELS. Reports to The Standing Advisory Committee on Trunk Road Assessment (SACTRA) Department for Transport, UK
The IMREL and MUSSA models are representative of the single-input approach, whilst DSCMOD is representative of the two-input approach. DSCMOD has been developed by DSC since 1990 for the practical objective of adding a land use dimension to what would otherwise be transport-only studies. MUSSA (developed by Martínez and colleagues in Chile) is primarily a research tool. IMREL (developed by Anderstig and Mattsson in Sweden) has been used for both purposes. At least two transport modelling packages (TRACKS and TRANSTEP) have offered facilities to build similar static models, in addition to the many static models which were developed in the 1960s and 1970s.

All of these models are linked to separate and usually pre-existing transport models. IMREL and MUSSA estimate equilibrium patterns of land use corresponding with the accessibilities output by the transport model. In the case of MUSSA, the full process involves iteration between the land use model (MUSSA itself) and the corresponding transport model (ESTRAUS) within the future year represented. DSCMOD, in contrast, assumes that the “base case” land use forecast is in equilibrium with the “base case” transport strategy, and calculates changes in land use from the accessibilities produced by alternative transport strategies. In DSCMOD, these accessibility changes may be the only influence on location choice, or may be combined in a more complex mechanism with floorspace constraints and market clearing using rent adjustments. In MUSSA, the market process is critical, as the model has developed from research into the integration of different theories about residents’ and landlords’ choices.

These models are generally urban models. However, a regional employment version of DSCMOD\(^{10}\) has been developed which represents only employment and uses a measure of economic potential (accessibility factored by zonal employment) to relocate jobs.

MUSSA\(^{11}\) is similar to the Anas models discussed below in adopting a unified economic framework, and is closely connected to a four-stage transport model. Unlike any model considered so far, it represents firms rather than employment with demand for space determined by a willingness-to-pay measure. Households attempt to maximise their consumer surplus, while developers attempt to maximise the price paid. MUSSA is not, however, available as a commercial package.

**ENTROPY-BASED MODELS: LILT**

LILT\(^{12}\) (Leeds Integrated Transport package) is the main UK model of this type, and has been applied in Leeds, Dortmund and Tokyo (as part of ISGLUTI), and several other UK urban areas. However further developments of this model have ceased. A similar, but simpler, US model, DRAM/EMPAL\(^{13}\) has been widely applied at the urban level in the USA.

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\(^{10}\) Simmonds, 1992; Simmonds and Jenkinson, 1993

\(^{11}\) Martínez, 1992

\(^{12}\) Mackett 1979, 1983

\(^{13}\) (Putman, 1995)
LILT allocates exogenous totals of population, jobs and employment. It is based around a Lowry model formulation, linked to a traditional four-stage transport model. Households are allocated on the basis of travel to work, following a spatial interaction framework.

Employment is allocated on a different basis depending upon whether it is primary, secondary or tertiary, the former allocated exogenously, the latter two allocated on the basis of accessibility and population distribution. Note that market processes are not modelled, and linkages between economic sectors only figure via the basic/non-basic distinction. It models a closed system.

DRAM/EMPAL allocates households on a similar basis to LILT, and employment on the basis of a zonal attractiveness measure to the workforce and previous employment by zone. Like LILT there is no treatment of prices or markets, but in contrast to LILT there is no representation of land use supply, and less explicit treatment of time.

SPATIAL-ECONOMIC MODELS: MEPLAN AND TRANUS
MEPLAN\textsuperscript{14} and TRANUS\textsuperscript{15} are both commercial packages developed from a set of models devised at the Martin Centre at the University of Cambridge. Both MEPLAN and TRANUS have been applied in policy and research studies both in the UK and abroad since the 1980s. Each package includes both a land use model and a multi-modal transport model, and is usually implemented as a quasi-dynamic model. There are many similarities in the broad approach adopted by the two packages, to the extent that for policy analysis purposes they can be treated as one. This review concentrates on MEPLAN, both because this information is more readily available and because (as far as we are aware) TRANUS is rather less developed in its treatment of economic relationships.

MEPLAN differs from models discussed so far in that the land use and transport elements are fully integrated. The interactions (‘economic trade’) between activities are determined by input-output analysis, and these interactions are used to derive the demand for transport. Location choices, transport mode choices and assignment are determined by a consistent multi-level logit choice structure based on random utility theory. The location behaviour of households, firms and property developers is based on competitive markets, with incomes and rents determined endogenously in each time period.

In urban applications of MEPLAN (such as LASER\textsuperscript{16}) particular attention is paid to residential location and the journey to work, shopping and schools. For regional implementations, emphasis 2 See the 1994 special issue of the journal Environment and Planning B containing urban and regional modelling papers from the Martin Centre 25th Anniversary Conference (see note to the references) is also placed upon industrial location and movements of freight from producers to consumers, with explicit modelling of the regional economy.

\textsuperscript{14} (Echenique et al, 1990)
\textsuperscript{15} (de la Barra, 1989)
\textsuperscript{16} (Williams, 1994, or ME&P, 1995)
A new easy-to-use package MENTOR, designed specifically for local authority use in the UK, is currently being tested. MENTOR is a pure land use package that can be interfaced to existing transport models. It builds on the theoretical structures of MEPLAN but operates at a more detailed level of segmentation of activities and is more straightforward to set up and calibrate. It retains the key characteristic that the distribution of transport demand is explicitly derived from the interactions modelled within the land use model.

3.4 Industrial Location Decisions

3.4.1 Policy needs

Firms decide on a location on the basis of different inputs. It is a long-term decision and choices made will reach far into the future for many firms. When new infrastructure is introduced that reduces general travel cost in a region, we rarely see any immediate effect on the location or relocation of firms, but the effect may be larger after a while when firms realise the potential benefits of the change in the infrastructure. It may be difficult to find empirical evidence of how infrastructure investments have influenced the location decision of firms. It has, for example, not been possible to find relocation effects of the Great Belt bridge linking East and West Denmark.

The reason why it is difficult to find hard evidence of any infrastructure impact on location decisions is that accessibility and distance to the market are not the only factors that determine choice. The immediate cost of land (land rent) is another direct cost element that plays an important role. In addition to direct financial factors, there are other factors as well, including access to the labour market, historical reasons for a specific choice, legislative considerations, agglomeration effects, availability of raw materials and other production inputs, company tax, etc. It is not possible to say which of the many factors play the most important role. The decision to relocate is often prompted by a combination of effects.

For policy-makers it is not the exact location decision for individual firms that is relevant. They much rather want to know which of many different policies will affect that decision. From an aggregate point of view, the interesting thing to know is the effect on location decisions in general (e.g. the number of jobs being relocated or created). This information is relevant in order to develop policies aimed at making industry locations attractive at the local, regional or national level.

Because location decisions by firms are influenced by so many factors, it is difficult to design empirical models that can provide relevant information to policy-makers. The decisive factor for one industry is not necessarily a decisive factor for another industry. Moreover, it is not easy to obtain the data necessary to describe those factors, many of which are qualitative in nature (e.g. choice of location for historical reasons). As shown in Table 3-16, only one model listed in the MDir model directory addresses this issue.
The number of theoretical models based on the location theory approach is enormous. However, analytical models focus mainly on economic relationships and try to determine an optimal location based on transport costs (distance to own market and input market), cost of land, production costs in general. This is used in Alfred Weber’s theory of location decisions, which has formed the basis for many theoretical models of location decisions.

The location of industries, on the other hand, also plays an important role in determining the demand for transport. In short-term models it is assumed that the location of firms (and households) remains fixed and unaffected by a given policy. This means that any effects identified will only be those happening as a direct consequence of the policy. In the longer run, the choice of location will be affected by cost changes and the demand effects of the policy will change as well.

The assumption of fixed location is not suitable for travel demand forecasting. The specific location is a prerequisite that must first be established before actual demand can be calculated. Models that can determine the location of production can be used in this context. Economic models can do this to some extent, in that location of production is determined by interregional trade. In models of this kind, it is assumed that production is mobile and will move to wherever demand is higher. On the other hand, production and costs are often determined on the basis of the price of input factors (rent and wages), which in turn may reduce flexibility of production and have a knock-on effect on demand.

To make an economic demand model usable, monetary demand is transformed into a physical demand for transport. This is typically done by traditional transport models, which take economic activity (e.g. GDP or trade patterns) as a basis for deriving origin-destination trip matrices. Hence, any change in trade patterns as a result of changes in location will influence trip patterns. The model approach and specificities that are relevant here are closely related to those described in Demand analysis in Section 3.2.

The relationship between location decisions and transport is similar to the one analysed in Land use planning. The interaction between activities and the planning of activities at specific geographical locations and the effects on transport demand, and the opposite chain of consequences is one way of describing the industrial location impact on transport demand, and the impact of infrastructural changes on location decisions. However, land use-transport relationships are not developed for industry output movements, but primarily for passenger transport, which is one of the production inputs.
Table 3-17: Transport models for industrial location decision analysis to regional detail and passenger/freight

<table>
<thead>
<tr>
<th></th>
<th>Regional detail</th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
<td>urban/regional</td>
<td>national models/regional</td>
<td></td>
</tr>
<tr>
<td>Passenger/freight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>not known passenger</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>passenger</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>freight</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>both</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

3.4.2 Organisation

The following organisational issues are important in developing models for industrial location decisions:

- **Budget, planning, ambitions**: location decisions are not the central focus of transport analysis. Location decision models will have to take this into account and either be taken from other studies or be kept simple. Certain models can be used as approximations for future location of production (e.g. SCGE models). Accordingly, the emphasis should be placed on how these results can be used as inputs for forecasting models. If location models are not available, simple econometric models can be used to forecast future developments in regional production based on historical changes. Location modelling is linked to the development of land use models. There have been explicit analyses of how land use patterns influence transport, but the exact location decision of individual firms often is not modelled.

- **Project organisation**: There are many elements that influence location decisions; it may be relevant to involve industry stakeholders to provide insights into the decision criteria of various industries. The scientific community and private institutions may be involved as well in order to better establish the relationships between location and transport and/or use of economic models. Stakeholders from the main project group (if different from the location decision objective) should be involved to keep an eye on the primary objective of the modelling task. The academic community, where land use models are most often developed, should be involved to ensure the relationship and operation of the model.

- **Scope and type of model**: For transport demand forecast purposes, it may be sufficient to use existing economic (equilibrium) models to predict the future location of production and location of demand for industry outputs. In the other direction where the industrial location as a function of transport investments and/or policies, small theory-based models may be able to provide the required insights. It has traditionally been difficult to establish these relationships empirically, hence very sophisticated models may not be the solution.

- **Choice of software/GIS**: the software used to develop the economic model must also be capable of predicting the future location of production. GIS is very useful as a data administrator and to display results (changed industry locations).
• Establish maintenance procedure: the economic model needed is a long-term equilibrium-type model. The relations of models of this kind are assumed to be rather stable, which means that updates of the model structure and parameters may not be required. On the other hand, models are calibrated to specific base years (unless a time-series econometric model is used) and updating of calibration parameters may be needed at regular intervals.

• Tendering: a strong partnership with relevant academic experts and model practitioners is required. Such a partnership or consortium can often be identified without a major tendering procedure.

Table 3-18: Transport models for industrial location decision according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th>passenger/freight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>not known</td>
<td></td>
</tr>
<tr>
<td>passenger</td>
<td></td>
</tr>
<tr>
<td>freight</td>
<td></td>
</tr>
<tr>
<td>both</td>
<td></td>
</tr>
<tr>
<td>road</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/iww/se</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
</tr>
</tbody>
</table>

3.4.3 Model development

As already mentioned there has not been a long tradition of specific empirical location modelling projects. Location is modelled as a part of larger modelling complexes such as the land use-transport interaction (LUTI) models. Location takes transport costs and the price of dwellings as a primary input to the location decisions, but empirical studies indicate that the elasticity will differ substantially between industries and also between firms of same type of industry. The decision criteria are a compromise between many elements. Which of the many criteria that is the decisive factor depends on what has happened in the past.

The modelling of location choices and the relation to transport is in theory approached through the land use-transport interaction models (many examples are provided in Section 3.4). Land use transport computer models simulate the working of two inter-related markets: the land market and the transport market using two interactive systems with feedback loops.

Households and firms demand dwellings and floor-space at different locations. The interaction with available supply will determine the price of buildings. Differences between supply and demand will change prices, which in turn will affect the demand for locations of households and firms. The computer model performs several iterations until prices stabilise. Once the location of households and firms is established, the transport sub-model estimates the number of trips for different purposes (work, shopping, education, etc.) and by different modes of travel (car, public transport, cycling and walking). These trips are assigned to the transport network and the model also calculates any delays likely to occur on the network due to congestion. Again, like the land use sub-models, several iterations are performed until no further changes in the use of modes arise due to traffic congestion. The resulting generalised transport costs (including out-of-pocket expenses and value of time) are fed back into the land
use sub-model to determine the accessibility of the locations, which in turn determines the attractiveness to households and firms. The model is 'cycled' forward into the future to represent the interaction between land use and transport. The following diagram schematically shows the simulation process in a land use-transport computer model.

![Diagram of land use-transport simulation model](image)

**Figure 3-6: Schematic representation of a land use-transport simulation model**

Typically, the inputs and outputs of land use-transport models are the following:

**Inputs in the model**
- Planned number of dwellings and business floor-space projections per model zone
- Employment forecast by industry per model zone
- Total economically active and inactive population, and total number of households by size for the modelled area from Census projections
- Car ownership at sub-regional level
- Transport improvements, costs and capacities

**Outputs from the model**

**Land use**
- Location of households per zone by socio-economic group
- Employment per zone by industry
- Rents per zone
- Costs of living per socio-economic group
- Costs of production by industry

**Transport**
- Travel volumes, times, and costs on the transport networks by mode of travel
Model examples
As previously mentioned, the location decision is not included as a primary objective in any of the models listed in the MDir directory, except one. The location decision is very often contained in land use models, of which there is a larger number of examples. Some of these examples are highlighted in Section 3.4.

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowrian Model</td>
<td>U \ R</td>
<td>Italy</td>
<td>RESPONSE suite</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

3.5 Ex-ante policy analysis

3.5.1 Policy needs
Ex-ante policy analysis is a process that supports the preparation of proposals for renewing or new transport policy. Its purpose is to gather information and carry out analyses that help define objectives, to ensure that these objectives can be met, that the instruments used are cost-effective and that a reliable evaluation will be possible later. An ex-ante evaluation can take place at different levels of activity. The European Commission has formally adopted ex-ante evaluations and made them obligatory for expenditure programmes. A guide has been produced specifically intended to give advice on the ex-ante evaluation of expenditure programmes, but it is also encouraged that ex ante evaluations be used for policies, projects, and other types of activities. An ex-ante evaluation serves a number of goals:

1. it allows a proper appreciation of whether the proposed level of funding and resources are in accordance with the expected results and impact;
2. it allows a reliable ex-post evaluation, so accountability for results and impacts will largely depend on the definition of the objectives.

Transport models are an important tool for decision-makers involved in transport policy. They can be used to carry out ex-ante impact assessments of, for example, transport infrastructure projects and policy measures. In the decision-making process, it is important for the parties involved to have an idea of the response of infrastructure users to assess whether the goals of a policy measure will actually be achieved. Therefore, transport plans and investments are usually based on travel projections generated by transport models. The models are used to estimate the number of trips that will be made, given the economic conditions, land use and transport system at future dates. It is clear that no model can take into account all factors that determine travel behaviour, and hence perfectly replicate reality. All models are limited by their assumptions, factors, and alternatives that are explicitly included in the system of equations used by the models. However, models should be able to answer the specific policy

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questions for which they were designed and incorporate the most important factors that determine transport demand that have widely been identified as necessary.

For example, when dealing with transport issues on a European level, a wide range of policy issues will have to be addressed which have arisen from the policy goals of the European Union as well as individual member states. If a transport model is to be constructed at this level, it is clear that certain features will have to be incorporated to enable the model to address those policy issues which are important at this level of policy-making. More specifically, the models should be able to address the policy goals and measures stated in the White Paper on European Transport Policy for 2010, as well as those stated in national policy and infrastructure plans. The issues that need to be covered include:

- the impact on and future developments in freight transport, passenger transport,
- the impact on modal split and intermodality of transport,
- the economic feedback processes related to changes in accessibility and which have an effect on regional economies,
- the inclusion of networks in order to detail the transport and economic effects from a spatial point of view, and cost and time changes as part of the policy strategies.

To make the model operational, the model should preferably allow appropriate indicators to be calculated in relation to the different impact categories and policy goals, such as safety, emissions, noise, land use, and economic performance based on the output indicators of the transport model.

From a modelling point of view, there are also other issues to be addressed. A transport model should cover all modes of transport to allow an analysis of how much of freight and travel trips will shift between modes of transport as a result of a particular transport policy. The option to distinguish between short- and long-distance transport and transport purpose is also a desirable feature. Each transport model should be able to deal with the issue of induced traffic demand, which normally requires an economic sub-model to account for variable demand in transport. This is typically achieved by including a macroeconomic or regional economic model. Additional drivers of demand are the indirect economic effects that have to be taken into account by a separate model, if economic conditions suggest that not all transport benefits are captured by other assessment techniques, such as in the case of imperfect competition in the economy. Over the last few years, it has become clear that an important driver of transport demand is improved efficiency in logistics and the choice of location for logistics centres. Also, in recent years the choice of airports made by airline companies has been identified as an important driver especially of passenger transport demand. In terms of data, it is essential that the model uses the most recent data available. This is just a short list of requirements for a transport model, one that does not claim to be exhaustive. Rather it is a list of important factors that one has to bear in mind when developing a transport model.

In addition to European modelling, models can also be constructed on the national level; in the Netherlands, debates about the planning of new transport infrastructure have traditionally been characterized by endless discussions and piles of proposals and counterproposals. Each
proposal is accompanied by research reports, which are sometimes produced to fight other reports. The avalanche of reports may well overwhelm decision-makers. To facilitate the debate on transport infrastructure and create a transparent basis for decision-making, the Dutch Ministries of Economic Affairs and Transport in 1998 decided to commission a research study on this topic. The aim of the study was to develop and detail a shared approach for the “ex-ante” evaluation of investment proposals in the field of transport infrastructure. The main outcome of the study was a standardized societal cost-benefit analysis approach. A few months later, the Minister of Transport made the use of this evaluation method obligatory for all infrastructure projects of national interest. The method developed is called Research Effects of Infrastructure Investment. The transport models and scenarios used for the ex-ante evaluation are evaluated on their ability to address a certain policy question. For example, large-scale infrastructure investment projects should include a decent demand analysis according to standard micro-economic theory. This means that, in addition to “existing travellers” new and induced travellers should be able to be identified, which leads to the “rule of half” convention in cost-benefit analyses.

The table below shows the models specifically designed for ex-ante transport policy analysis. Most of them are on the regional/national level. In addition, most of them are designed for freight policy or cover both freight and passenger transport.

<table>
<thead>
<tr>
<th>Passenger/freight</th>
<th>Regional detail</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
<td></td>
</tr>
<tr>
<td></td>
<td>urban/region</td>
<td></td>
</tr>
<tr>
<td></td>
<td>national models/region</td>
<td></td>
</tr>
<tr>
<td></td>
<td>national models incl. international</td>
<td></td>
</tr>
<tr>
<td></td>
<td>international models</td>
<td></td>
</tr>
<tr>
<td>Passengers</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Freight</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Both</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

3.5.2 Organisation
The following organisational issues are important when developing a transport model for ex-ante policy assessment:

- **Budget, Planning, Ambitions.** Large-scale projects/policies for which ex-ante analyses are used will usually come under public and academic scrutiny. This means that models should be able to predict the possible effects of a policy, and for different stakeholders as well (e.g. environmental impact or wider external effects). This means in terms of budget and planning, a considerable budget and ample time should be reserved. In most cases, if a national model containing part of the effects is available, it can be used and extended to cover missing parts of the analysis. Sometimes, other agencies (mostly funding agencies) may also require a thorough ex-ante analysis, including the World Bank or European Investment Bank or the European Commission.
Project organisation. The construction of a large model covering different levels of specialty also requires setting up a steering group to monitor the work. The larger the steering group, the more complex this will be.

Scope and type of model. For example, TRANS-TOOLS aims to overcome several shortcomings of current transport models and proposes specific steps to overcome these. Shortcomings include the unsatisfactory representation of traffic mixes (short/long distance and freight/passenger), absence of intermodality and freight logistics in some models, differences in the implementation of Origin-Destination base years for freight traffic in some models, the outdatedness of some models, in terms of either model design or database, and insufficient linkage of network-based transport models to socio-economic and external effects. Some models also insufficiently cover the networks of the new member states. Level of service in relation to the measurement of congestion on the network is in many cases not sufficiently represented.

Choice of software/GIS. GIS systems are very helpful in making the results of an ex-ante analysis visible for policy-makers.

Establish maintenance procedure. For ex-ante studies, it is important that a maintenance procedure is developed so that an effective ex-post analysis can be carried out. In the case of Storebelt, for example, traffic was monitored after the link between Sweden and Denmark opened and actual traffic could be compared to the predicted traffic.

Tendering. A project comprising ex-ante analysis is usually organised around the different types of expertise needed. For example, if it includes a financial and economic analysis, financial and CBA experts will be hired or, in some cases, specialist accounting and auditing firms. Understandably, an environmental assessment (or biodiversity assessment) will require environmental specialists. The core of a team dealing with ex-ante transport studies is usually formed by transport experts.

The table below shows the models for ex-ante policy analysis by mode and scope. Most freight models involve multimodal issues, i.e. issues covering more than one mode.
Table 3-21: Transport models for ex-ante policy analysis according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th>Modes</th>
<th>passenger/freight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>passenger</td>
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<tr>
<td>not known</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>road</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/iww</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/air</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/slow</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/iww/sea</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/iww/sea/air</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>

3.5.3 Model development

Models for ex-ante policy analysis are developed because there is a certain problem with a policy that needs urgent resolving, such as taxation or an infrastructure investment. The TRANS-TOOLS model has been constructed to improve on previous European models. It is a European transport network model covering passenger and freight which no longer has the shortcomings of current European transport network models. The objective of the model is to build upon the experience of existing transport models and provide a basis for developing an integrated transport policy support tool at EU level. The software can be used to make scenario forecasts for future years allowing scenarios to be defined by changing the key policy parameters. The model is free of individual property rights, so policy-makers can freely use it as a decision tool in European transport planning, which is also a novelty for a model at this level. The philosophy of the model is to build upon the models available and developed and applied by the project partners so as to address European policy issues. If no model is available in a country, it would be worth using TRANS-TOOLS because it provides regional details for all EU countries (except for Bulgaria and Romania, which are still on country level).

The TRANS-TOOLS model links a number of models in a single software-based model. The core parts of the model are the NEAC model for freight transport and VACLA V model for passenger transport, which have been used in combination for the TEN-STAC project. The model will be refined by including a spatial computable general equilibrium model, CGEurope, a traffic assignment model, and a logistics model, SLAM. The model covers the enlarged EU plus the countries which have acceded and those along the borders of the EU. It is envisaged that the freight model will integrate the new member states and accession countries at the same zoning level as the EU-15, which is covered on NUTS-2 level and NUTS-3 zones in the passenger model. A novelty will be the introduction of feedback from the economy by integrating the spatial CGE model CGEurope and linking it to the freight model to capture the indirect economic effects of changed accessibility and relative goods prices that arise from network improvements and transport policies. The database of TRANS-TOOLS is based on the ETIS-BASE data set, which delivers a harmonised dataset of freight and passenger transport O-D data and socio-economic data for the most recent year possible. These O-D matrices also provide the possibility of modelling intermodal transport flows and
transport chains. At the flow level, not only flows within Europe are considered, but also intercontinental flows, which are an important driver of demand especially in freight transport. As for traffic assignment, the model uses a stochastic user equilibrium approach. See section 13.4.2 of part 3 and section 6.2 of part 4 for an example of stochastic user equilibrium assignment. To model congestion effects on the network that also affect long-distance travel, we are considering linking local transport in metropolitan areas.

Table 3-22: List of models from MDir that can be used for ex-ante policy analysis

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kessel &amp; Partner model</td>
<td>U \ R</td>
<td>Germany</td>
<td>ISG</td>
<td>N \ I</td>
<td>Netherlands</td>
</tr>
<tr>
<td>ASTRA</td>
<td>I</td>
<td>EC</td>
<td>SISD</td>
<td>N \ R</td>
<td>Italy</td>
</tr>
<tr>
<td>Hamburg freight model</td>
<td>U \ R</td>
<td>Germany</td>
<td>EUNET Assessment model</td>
<td>N \ R</td>
<td>Greece</td>
</tr>
<tr>
<td>Scenario Explorer</td>
<td>N \ R</td>
<td>Netherlands</td>
<td>TENASSESS Barrier Model</td>
<td>NK</td>
<td>France</td>
</tr>
<tr>
<td>(Scenarioverkenner)</td>
<td></td>
<td></td>
<td>TENASSESS PAM</td>
<td>NK</td>
<td>France</td>
</tr>
<tr>
<td>PACE-FORWARD</td>
<td>N \ R</td>
<td>Netherlands</td>
<td>ATIS- Transalpine pilot study and demonstrator, D10 MESUDEMO</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>Prometeia</td>
<td>N \ R</td>
<td>Italy</td>
<td>TRANS-TOOLS</td>
<td>I</td>
<td>EC</td>
</tr>
<tr>
<td>STAN (Norway)</td>
<td>N \ R</td>
<td>Norway</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMP</td>
<td>N \ R</td>
<td>Spain</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

3.6 Investment Analysis

3.6.1 Policy needs

Is it a good idea to invest? Is this investment better than the other one to resolve a particular issue? What are the benefits and costs of the investment? Can they be compared and what is the outcome? These and many other questions will be asked when political decisions have to be made about investments in transport infrastructure. Decision-makers and private investors (e.g. the European Bank for Reconstruction and Development – EBRD) will want to know the feasibility of projects that are proposed to address certain issues (reducing congestion, economic development in depressed regions, increasing traffic safety, etc.). They will want to know whether the benefits of the investment will justify the costs.

Transport appraisal involves assessing whether transport projects and policies will provide value for money. This definition raises many questions – assessment by whom, for whom, from what perspective, and at what stage. One of the features of transport decisions is that they typically impact on many parties – transport operators, individual transport users, shippers, local residents and businesses, land and property owners, national and local taxpayers. Each of these stakeholders will seek to assess the impact of a project from the perspective of his/her own interest. But, the overarching perspective of transport appraisal
needs to be a social one, that is, one which takes account of significant impacts of the project or policy on whoever is affected. So the key question which the appraisal seeks to address is:

Is a project or policy intervention worthwhile from an overall social point of view?

Many of the issues raised in Section 3.5 on Ex-ante policy analysis are also important here. Investment analysis models - or tools, to put it more precisely - are sometimes developed for each project separately based on theoretical descriptions of the methodology. However, the main benefit for the political decision-making process arises when a generic tool is used, where assessments are undertaken with the same elements involved and using the same parameters and so on for all projects. Only then will comparisons across projects make sense.

The kind and extent of the impact of a given infrastructure can be large. New infrastructure will influence traffic directly by improving travel flow conditions and higher speeds. However, the infrastructure may also influence other aspects, such as increased emission and noise levels as well as other environmental impacts. Barriers may be created and the landscape may change. It is necessary to take such elements into account when evaluating the changed infrastructure. The changes in the different elements cannot immediately be compared because they are not measured on the same scale (e.g. tonnes of emitted CO₂ versus 20 minutes of reduced travel time). It is necessary to adopt an approach where different impacts are measured on the same scale and can be compared. A cost-benefit analysis is such a methodology, where benefits and costs are measured on a monetary scale. Some inputs to this evaluation are already measured in financial terms – such as construction costs and changes in fuel expenses – but most impacts are not quantified in monetary terms – travel time reductions, increased noise, increase in number of accidents, etc.

Transport models provide an important input for the assessment of transport infrastructure investments. Model calculations give estimates on changes in travel times, number of trips, vehicle kilometres for different transport modes. This information is essential when calculating the environmental impact and the impact in terms of noise and safety, as well as what is probably the most important effect – travel time savings. In most cases, transport models will have to be used which include networks in order to give a more accurate prediction as to where changes in traffic will occur and what the extent of these changes is likely to be. There is, for example, a considerable difference between the environmental and noise impact of an increase in traffic on a motorway in a rural area than in a densely populated urban area.

Another important aspect to be covered is the monetary values that are applied to convert physical changes into monetary changes. The estimation of these key parameters has been investigated in numerous studies around the world and the values used differ from country to country and region to region. The European ExternE and HEATCO projects provide estimates for a large number of key parameters: emission factors and values of tons of emitted substances and the value of travel time (VoT) based on studies in the member countries as well as independent new studies. The HEATCO project also gives good practice guidelines for the assessment of infrastructure projects.
The appraisal methodology used is often a cost-benefit analysis (CBA), which assumes that all effects from a given infrastructure investment can be measured by the direct impacts, such as changes in traffic flows and the environmental and other effects arising directly from these flows. However, a CBA analysis uses rather strict assumptions that are not necessarily fulfilled in reality, the most important one being the assumption of perfect competition in all economic and other markets involved. This implies that all changes will be reflected in market prices that can be observed. All changes can then be calculated using these prices. Due to imperfections, however, there may be effects that are not directly covered by these prices. For example, an imperfect labour market may affect employment in unforeseen ways not accounted for in changed travel demand. Similar unforeseen impacts on interregional and international trade as a result of trade restrictions also mean that it is not entirely correct to make an assessment on the basis of the direct impact on travel demand.

Another politically interesting aspect is the distribution of costs and benefits. A CBA does not consider who the beneficiaries are and who is to foot the bill.

To deal with these imperfections and distributional effects, additional tools are sometimes used. They include spatial general equilibrium models (SCGE) and multi-criteria analyses (MCA). Both methods require quite a comprehensive model that must be developed as a separate extra activity. This is not often done. Instead, the CBA will be accompanied by a qualitative analysis of the non-market-non-valued effects as well as using approximations to take into account the imperfections.

Table 3-23 shows the models specifically designed for use in an investment analysis. The number is small because transport models are used primarily for other purposes, but they deliver crucial inputs to the investment analysis without having this as their immediate objective.

<table>
<thead>
<tr>
<th>Passenger /freight not known passenger</th>
<th>Regional detail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban / regional</td>
<td>national models / regional</td>
<td>national models incl. international</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

3.6.2 Organisation
The following organisational issues are important when developing an investment analysis tool:
- **Budget, Planning, Ambitions.** Usually existing transport models are used to develop/evaluate changes in transport demand (modal shift, route choice, etc.). As such, an investment analysis is not a priority objective when constructing a transport model. However, when a transport model is available, then the outputs are essential to the assessment.

- **Project organisation.** Stakeholders at the relevant decision level (local, regional, national) should be involved to provide the necessary relevant definitions of the investment project. Consulting firms/institutions operating relevant transport models should also be involved.

- **Scope and type of assessment tool.** In the case of small-scale investments, not all types of effect will need to be considered. Indirect effects, in particular, can be expected to be minimal in small projects. The greatest potential will be to apply a generic tool for all projects. This ensures that no effects are overlooked and that effects are treated similarly for all projects. The methodology may have to be adjusted to reflect the scale of the project.

- **Choice of software/GIS.** There is no immediate software requirement. It is sometimes convenient to use spreadsheets to present results and, as a generic tool, to structure inputs and outputs. GIS is only usable to present the inputs for use in the analysis.

- **Establish maintenance procedure.** Key parameters must continuously be updated for a generic tool to reflect current values (because they are measured in monetary terms). Maintenance should be carried out at a central decision level and the tool should be provided to all organisations conducting an investment analysis.

- **Tendering.** A project comprising CBA is usually organised around different types of expertise needed. For example, if it includes a financial and economic analysis, financial and CBA experts will be hired or, in some cases, specialist accounting and auditing firms. Understandably, an environmental assessment (or biodiversity assessment) will require environmental specialists. The core of a team dealing with ex-ante transport studies is usually formed by transport experts.

### Table 3-24: Transport models for investment analysis according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th>modes</th>
<th>not known</th>
<th>passenger</th>
<th>freight</th>
<th>both</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/air</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>road/rail/iww/sea</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>road/rail/sea/air</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>
3.6.3 Model development/method

To carry out a cost-benefit analysis (CBA), the HEATCO project recommends that the following 15 general principles be considered when designing the assessment methodology:

1. **Appraisal as a comparative tool.** To estimate the costs and benefits of a project, one has to compare the costs and benefits of two scenarios: the ‘Do-Something’ scenario, where the project being assessed is going to be realised, and a ‘Do-Minimum’ scenario, which needs to be a realistic base case describing future developments. If there are several project alternatives, a scenario must be created for each alternative and all scenarios must be compared with the ‘Do-Minimum case’.

2. **Decision criteria.** We recommend using NPV (net present value) to determine whether a project is worthwhile or not. In addition, depending on the decision-making context and the issue to be addressed, BCR (benefit/cost ratio) and RNPSS (ratio of NPV and public sector support) decision rules could be used.

3. **The project appraisal evaluation period.** We recommend using a 40-year appraisal period, with residual effects being included, by way of default evaluation period. Projects with a shorter lifetime should, however, use their actual length. To compare potential future projects, a common final year should be determined by adding 40 years to the start year of the last project.

4. **Treatment of future risk and uncertainty.** To assess (non-probabilistic) uncertainty, we consider a sensitivity analysis or scenario technique to be appropriate. If resources and data are available for probabilistic analysis, a Monte Carlo simulation analysis can be conducted.

5. **Discounting.** We recommended adopting the risk premium-free rate or weighted average of the rates currently used in national transport project appraisals in the countries in which the TEN-T project is to be located. The rates should be weighted with the proportion of total project finance contributed by the country concerned. In lower-bound sensitivity analyses, in order to reflect current estimates of the social time preference rate, a common discount rate of 3% should be utilised. For damage occurring beyond the 40-year appraisal period (inter-generational impacts), e.g. for climate change impacts, a declining discount rate system is recommended.

6. **Intra-generational equity issues.** We recommend developing at a minimum a “winners and losers” table and present it alongside the results of the monetised CBA. Distributional matrices for alternative projects may be created and compared. Additionally, stakeholder analyses should be undertaken as well. We recommended using local values to assess unit benefit and cost measures.

7. **Non-market valuation techniques.** If impacts found in transport project appraisals cannot be expressed in market prices, but are potentially significant for the overall appraisal, we recommend that – in the absence of robust transfer values – non-market techniques to estimate monetary values should be considered. The choice of technique used to value
individual impacts should be dictated by the type of impact and the nature of the project. However, Willingness to Pay (WTP) measures are preferable to cost-based measures. Values should be validated against existing European estimates.

8. **Value Transfer.** Value transfer means using economic impact estimates from previous studies to value similar impacts in the present appraisal context. Value transfers can be used when insufficient resources for new primary studies are available. The decision as to whether to use unit transfers with income adjustments, value function transfer and/or meta-analyses will depend on the availability of existing values and experience to date with value transfers related to the impact in question.

9. **Treatment of non-monetised impacts.** We recommend, at a minimum, that if impacts cannot be expressed in monetary terms, they should be presented in qualitative or quantitative terms in addition to evidence of monetised impacts. If only a small number of non-monetised impacts can be assessed, sensitivity analysis may be used to indicate their potential importance. Alternatively, non-monetised impacts may also be included directly in the decision-making process by explicitly eliciting decision-maker’s weights for them.

10. **Treatment of indirect socio-economic effects.** We recommend that if indirect effects are likely to be significant, an economic model, preferably a Spatially Computable General Equilibrium (SCGE) model, should be used. Qualitative assessment is recommended if indirect effects cannot be modelled due to limited resources (high costs for the use of advanced modelling), insufficient availability of data, or lack of appropriate quantitative models or unreliable results.

11. **Marginal cost of public funds.** Our recommendation is to assume a marginal cost of public funds of 1, i.e. not to use any additional cost (shadow price) for public funds. Instead, a cut-off value for the RNPSS of 1.5 should be used when relevant.

12. **Producer surplus of transport providers.** We recommend estimating (changes in) the producer surplus generated by changed traffic volumes or by the introduction and adjustment of transport pricing regimes.

13. **Accounting procedures.** a) Factor costs should be the adopted unit of account. This requires measures expressed in market prices – which include indirect taxes and subsidies – to be converted to factor costs. b) We recommend converting all monetary values into € at a price level for a fixed year. However, monetary values should be adjusted with the Purchasing Power Parity (PPP). c) Monetary values, i.e. preferences, for non-market goods like reduced risk of falling ill or reduced damage to the environment will increase with increasing income; thus we recommend increasing monetary values on the basis of GDP growth.

14. **Updating of values.** The unit values supplied in this report represent state-of-the-art values for the individual impacts addressed. Nevertheless, all values will be subject to change as new empirical evidence becomes available and methodological developments occur. As a consequence, we recommend that values are reviewed and updated on a regular basis e.g. after three years maximum.
15. Presentation of results. As far as possible, impacts should be expressed in both physical and monetary terms. The results of the sensitivity analysis and the non-monetised impacts should be reported along with the central monetised results.

Table 3-25: List of models from MDiR that can be used for investment analysis

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATISSE I</td>
<td>I</td>
<td>France</td>
<td>STREAMS</td>
<td>I</td>
<td>Western Europe</td>
</tr>
<tr>
<td>East-West</td>
<td>N \ R</td>
<td>Denmark</td>
<td>Evaluation model concerning the freight transport corridor between Italy and Greece</td>
<td>NK</td>
<td>Greece</td>
</tr>
<tr>
<td>Traffic Model</td>
<td></td>
<td></td>
<td>Model for the ex-post evaluation of infrastructure investments in Greece financed by the Structural Funds</td>
<td>NK</td>
<td>Greece</td>
</tr>
<tr>
<td>T-NETWORK</td>
<td>I</td>
<td>Italy</td>
<td>Evaluation model for Phare-financed transport programs in 10 Central and Eastern Europe candidate member states</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>ETRANFOM</td>
<td>U \ R</td>
<td>Italy</td>
<td>RESPONSE suite</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Road Fund Model</td>
<td>N \ R</td>
<td>Czech Rep</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

3.7 Modal shift

3.7.1 Policy needs

Modal shift is seen as a means of reducing road transport by shifting part of the traffic to other less polluting and less congested modes of transport. This can be applied to both freight and passenger transport. Modal shift policy ranges from supply-to-demand policies to push-and-pull strategies. Supply side measures may include investing in infrastructure that forms an alternative to road transport; demand side policies can range from road pricing to share and ride through to logistical innovations in freight transport. The Dutch ministry of transport has launched a freight transport programme on company level to encourage transport companies and shippers to carry out transport more efficiently (with fewer kilometres and/or less fuel consumption). Initially, the programme focused too much on encouraging modal shifts, which were not necessarily more efficient. Recently, the focus has changed to more efficient transport, taking account of the wider economic environment, meaning that that packaging techniques and logistics can now also be included. Moreover, the European Commission has introduced a programme to encourage modal split, called Marco Polo, which provides incentives depending on the tonne-kilometres transferred to modes other than road transport.

In some cases, transport modelling is needed for policy-making in order to evaluate the effectiveness of the policy. If expensive measures are developed for just a small population of shippers/transporters in the case of freight transport, or for groups of passengers in the case of passenger transport, then other policies might be less expensive and more effective in mitigating the external effects of road transport. For example, a comprehensive European project has shown that policy scenarios, including White Paper modal shift measures (targeted investments in rail and inland waterways), fail to lead to modal shift effects in passenger
transport on a European level, while the modal shift effects on freight transport are very modest on a European level. In some cases, modal shift as a way of achieving environmental gains seems to be more promising when encouraged in urban areas.

White Paper infrastructure proposals hardly lead to modal shifts on a European level. At the heart of the White Paper is a desired modal shift from road and air to rail and inland waterways. Modal shift is viewed in the White Paper as an important means to achieve economic, social and environmental goals. The environmental impact of the shift as expressed in lower emission levels observed in this research program is very small. The study reveals that if other environmental effects of new infrastructure (e.g. dedicated freight rail lines) are taken into account (e.g. noise and adverse impact on nature/landscape), it is not at all certain that the modest modal shift predicted in the White Paper policy scenario will be environmentally beneficial.

The White Papers notes that increased traffic and urban congestion will result in more air and noise pollution and accidents. In the White Paper, the Commission promotes ‘good urban practice’: more and better public transport in urban areas. European research projects, like Transecon and PROPOLIS, have shown that if economic, social and environmental goals are to be pursued in urban areas, it would seem particularly effective to use the White Paper investment proposals for improved public transport in combination with such other instruments as pricing policy (as proposed in the White Paper) and pollution source policy. Policy mixes of this kind could result in, for example, the desired modal shift from car to public transport and bicycles, one of the impacts contributing to urban social, economic and environmental benefits.

As previously stated, modal shift is a confusing policy indicator. On the one hand, it is not certain that modal shift policy proposals will have an effect on modal shift and benefit the environment. On the other hand, it does not mean that all White Paper modal shift proposals are ‘bad’ policies per se. For example, investing in a specific dedicated freight rail line could lead to hardly any modal shift at all. The investment may nevertheless be beneficial to the economy. Because of the confusing nature of the modal shift indicator, it may be advisable to abandon the general modal shift aims altogether. It would seem clearer to design and evaluate transport policy proposals directly on their potential contribution to meeting desired economic, social and environmental end goals, using techniques such as societal cost-benefit analysis and strategic environmental impact analysis. The European Commission, too, has abandoned the modal shift terminology in favour of co-modality.

The table below shows the models specifically designed for modal shift policy analysis. Only two models have been developed for this issue, both of which are large-scale models covering either freight or freight and passenger transport.
Table 3-26: Transport models for modal shift analysis according to regional detail and passenger/freight

<table>
<thead>
<tr>
<th>Regional detail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
</tr>
<tr>
<td>Passenger not known</td>
<td>0</td>
</tr>
<tr>
<td>Passenger known</td>
<td>0</td>
</tr>
<tr>
<td>Freight</td>
<td>0</td>
</tr>
<tr>
<td>both</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
</tr>
</tbody>
</table>

3.7.2 Organisation
The following organisational issues are important when developing a transport model for ex-ante policy assessment:

- **Budget, Planning, Ambitions.** Usually existing models are used to develop/evaluate modal shift policy. As such, this policy is not a priority objective when constructing a transport model. However, when a transport model is available, the general efficiency of the policy can be evaluated. The White Paper was analysed using the SCENES model combined with realisation data in order to evaluate the policy ex-post.

- **Project organisation.** Usually when evaluating modal split it is good practice to have stakeholders within the project organisation. The outcome of the models are mostly too aggregate and too coarse as to the level of detail so that it can be supplemented with case-specific information.

- **Scope and type of model.** All models that capture modal shift effects should be multimodal and/or intermodal in nature. Push and pull measures should be incorporated into the model for each specific policy.

- **Choice of software/GIS.** This is no different than for other models. GIS can be useful to present the results to stakeholders.

- **Establish maintenance procedure.** For modal split policies, maintenance is not so much the issue. It would be helpful for ex-post policy evaluations.

- **Tendering.** A project which includes modal shift policies usually requires an evaluation team to monitor whether the right segments are selected. Transport modelling usually plays a minor role in developing modal split policies.

The table below shows the models for modal shift policy analysis by mode and scope. As can be observed, they are all multimodal models.(covering more than 1 mode).
Table 3-27: Transport models for ex-ante policy analysis according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th>Modes</th>
<th>passenger/freight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
<td>passenger</td>
</tr>
<tr>
<td>road</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/iww</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/sea</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/iww/sea</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

3.7.3 Model development

Models for modal shift should incorporate the choice of more than 1 mode of transport, therefore the modal split model is an important element in modelling the modal shift. The difference between passenger and freight modal split modelling is that in passenger transport the traveller usually takes the decision to travel. In freight, the decision to ship goods by a specific mode can be taken by multiple parties (this can be the sending or receiving shipper and/or the logistics service provider), depending partly on the characteristics of the shipment. It is difficult to reproduce this decision process in a freight transport model. The SMILE model\(^{18}\) tries to capture part of the complex decision process in freight transport. This approach allows a modal shift policy to be better evaluated. Besides multimodal transport modelling, intermodal transport is also an important issue (intermodal means between modes). For example, the choice for airline transport will be accompanied by a decision on access and egress transport. This means that, in order for this aspect to be captured, the change between modes within a journey should also be modelled. In the case of passenger transport, this has already progressed. In the case of TRANS-TOOLS, access and egress transport for airline transport has been modelled for passenger transport.

Table 3-28: List of models from MDict that can be used for modal shift modelling

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>STREAMS</td>
<td>I</td>
<td>Western Europe</td>
<td>Polydrom/SICO</td>
<td>N \ I</td>
<td>Germany</td>
</tr>
<tr>
<td>NEAC</td>
<td>I</td>
<td>EC</td>
<td>NATFRE.10</td>
<td>N \ R</td>
<td>Greece</td>
</tr>
<tr>
<td>PACE-FORWARD</td>
<td>N \ R</td>
<td>Netherlands</td>
<td>East Branch of East/West corridor</td>
<td>N \ I</td>
<td>UK</td>
</tr>
<tr>
<td>Module Transport Nonurban de Marchandises</td>
<td>N \ I</td>
<td>France</td>
<td>ETRAFREIGHT</td>
<td>N \ I</td>
<td>Italy</td>
</tr>
<tr>
<td>Quinquin Fret</td>
<td>N \ R</td>
<td>France</td>
<td>ISG</td>
<td>N \ I</td>
<td>Netherlands</td>
</tr>
<tr>
<td>SNCF</td>
<td>N \ I</td>
<td>France</td>
<td>Polydrom/SICO</td>
<td>N \ I</td>
<td>Germany</td>
</tr>
</tbody>
</table>

\(^{18}\) The logistical model for Norway/Sweden that is currently under development and the RESPONSE suite also try to capture the decision process.
3.8 Infrastructure planning

3.8.1 Policy needs

The development of road transport in most European and Western countries can be compared to developments in Denmark from the 1960s until the 1990s. Therefore, the framework of objectives of road infrastructure planning set out below will be taken as being indicative for a common set of objectives in a number of countries (Leleur, 2000)\(^\text{19}\).

During the 1960s, a period characterised by economic growth and the widespread purchase of cars, the construction of a Danish national motorway system began. The relevant objective was expressed as A): vehicle mobility denominated by high and relatively undisturbed travel speed. Time savings and savings in vehicle operating costs were also part of the objective. The motorways were also constructed to achieve objective B): safety due to the fact that driving on motorways is far less risky than on other road types. A better understanding of the quality level of specific stretches was obtained by adopting what is known as the level-of-service (LOS) concept developed in the USA. This made it possible to give an explicit account of objective C): comfort, because existing routes in need of traffic relief could be described and systematically compared to actual LOS values. Another objective addressed was D): accessibility. Basically, road infrastructure should provide access to all parts of the country by means of a network with reasonably high mobility, safety and comfort.

In the mid-1970s, a number of new objectives appeared. Environmental factors became particularly influential. It was argued that new projects should not be appraised solely against the basic objectives described above. New appraisal methodologies incorporated objectives E): noise relief, F): traffic barrier reduction, and G): air pollution, each of them measured by different quantitative procedures developed.

The objectives mentioned can mainly be attributed to road infrastructure planning in rural areas. However, they also play a role in planning when circumstances are more complex. Of major concern here is an objective, which can loosely be identified as H): urban quality, that is to say, the way in which a new scheme will affect, for example, a neighbourhood functionally, socially, aesthetically and so on. In several cases, major new roads in large cities have only served to relocate congestion problems. The objective of urban quality should also play a role in smaller towns and villages. If that is not the case, totally unbalanced schemes could lead to the separation of areas and functions. Accordingly, it is important that road infrastructure planning should be coordinated with physical planning.

More recent objectives – if seen as explicit considerations – are I): economic life, trade and industry, and J): linking of regions. Included in the former objective are so-called logistical effects. If components needed in a production process can be delivered “just-in-time”, space for larger stocks can be reduced and savings obtained. Such logistical effects are closely tied to reliability of supply and based on transport regularity. The objective of linking regions has

turned out to be important in the Danish debate about constructing fixed links across belts. Both objectives have been found to be difficult to treat in a quantitative way, compared to the objectives previously mentioned. However, this does not imply that they are less important.

Transport is an integrated part of modern society. An objective such as K): mobility – or person mobility in contrast to vehicle mobility as previously mentioned (objective A) – can be used to express the gains for society and its citizens when particular functions can be developed and maintained by means of communication, with transport movements of persons and goods making up an important part. In addition to an economic interpretation of mobility, a social one can also be highlighted. Mobility is important in this respect as a lack of mobility can reduce the quality of life a reduction in the number of personal contacts. Mobility as an objective is difficult to attribute to particular elements in the transport network. This is why it is more adequately regarded as a system effect to be derived from the quality of the transport system, whether it be developed or less developed. Another system effect that can be mentioned is L): long-term environmental consequences due to accumulated damage to the environment, with transport being either the major cause or one of several contributing factors. An example is the severe acid rain damage to forests, which has been observed in Central Europe in recent years. An example where transport is a contributing factor is the “greenhouse effect”, which is due to an accumulation of CO₂ in the atmosphere. As can be seen with the set of objectives for road infrastructure planning, environmental considerations can be both of a local nature, as with objectives E, F and G, and of a national/global nature as is the case with objective L.

With regard to the development of the set of planning objectives, two trends have occurred. The first trend is that the vehicle mobility objective aimed at reducing travel time and vehicle operating costs has been supplemented by objectives concerning the nuisance caused by road traffic. These objectives appear as reducing the number of accidents and/or as a lowering of the environmental load on areas adjacent to the roads, for example as noise reduction. The second trend is that the objectives, from being connected specifically to road infrastructure improvement projects and their location and design, have been extended to include not only these local/regional impacts but also impacts of a national/global nature. Thus, impacts on economic life and trade and industry, and impacts connected to the linking of regions, can primarily be characterised as regional/national, while mobility and long-term environmental consequences are of national and global importance.

A total of 12 different Danish objectives are shown schematically in
Table 3-29. The regional/national type is a mixture of the local site-specific type and national/global systems type.
Table 3-29: Objectives for road infrastructure planning

<table>
<thead>
<tr>
<th>Local objectives</th>
<th>Regional/national objectives</th>
<th>National/global objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle mobility</td>
<td>Economic life, trade and industry</td>
<td>Mobility</td>
</tr>
<tr>
<td>Safety</td>
<td>Linking of regions</td>
<td>Long-term environmental consequences</td>
</tr>
<tr>
<td>Comfort</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise reduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrier effect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air pollution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban quality</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A basic concern in transport planning, and road infrastructure planning as one of its constituents, is the importance that is attached to increased mobility compared to the concomitant and accumulating long-term environmental consequences. An unambiguous direct political answer to this question can hardly be expected. However, political intentions and assessments indirectly be obtained from specific debates about individual studies and proposals.

Formulating planning objectives can serve two purposes. In addition to guiding planning efforts, for example by structuring the set-up of planning models, it can also be useful in that it makes normative judgments more explicit and open for debate.

Building on the Danish objectives, a number of common EU objectives have been formulated to develop a common transport policy (Holvad & Leleur, 2004). The list comprises a total of ten objectives, with each objective defined to represent a particular dimension not covered by the other objectives (ideally they are “orthogonal” to each other):

1. *Maximise transport efficiency* (improved performance and development of each mode and their integration into a coherent transport system, socio-economic feasibility, improved comfort and level of service, etc.)
2. *Improve transport safety* (vehicle and infrastructure safety, dangerous transports, driver education and behaviour, socio-economic feasibility, etc.)
3. *Contribute to environmental improvement* (local air pollution, noise, severance, quality of built environment and landscape, socio-economic feasibility, etc.)
4. *Improve strategic mobility* (accessibility and European networks, nodes, peripheral areas, missing links, etc.)
5. *Contribute to strategic environmental improvement* (greenhouse gases, ecological damage, use of energy resources, etc.)
6. *Contribute to strategic economic development* (regional economics, spatial planning considerations, etc.)
7. *Contribute to technological development* (innovation in transport technology and standards, telematics, etc.)
8. *Contribute to implementing the Single European Market* (fair competition and pricing, technical harmonisation, etc.)

---

9. *Contribute to the social dimension* equity, working conditions, “Citizens’ Network”, people with reduced mobility, etc.)

10. *Contribute to the external dimension* (network development and integration, agreements, technical assistance and co-operation, etc.)

The objectives were set out at the Transnational European level, which is why they may be in agreement/disagreement with specific national and/or local transport objectives. The ten objectives listed necessarily reflect general EU transport objectives, which can be achieved both by implementing infrastructure and technology projects and by implementing specific policies.

Table 3-30: Transport models for infrastructure planning according to regional detail and passenger/freight

<table>
<thead>
<tr>
<th>Regional detail</th>
<th>not known</th>
<th>Urban / regional</th>
<th>national models / regional</th>
<th>national models incl. international</th>
<th>international models</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger not / freight known</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>passenger</td>
<td>0</td>
<td>20</td>
<td>8</td>
<td>2</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>freight</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>15</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>both</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6</strong></td>
<td><strong>20</strong></td>
<td><strong>17</strong></td>
<td><strong>22</strong></td>
<td><strong>2</strong></td>
<td><strong>67</strong></td>
</tr>
</tbody>
</table>

3.8.2 Organisation

The following organisational issues are important when developing a transport model for infrastructure planning:

- *Budget, Planning, Ambitions.* Usually existing models are used to develop/evaluate infrastructure projects, e.g. a new road. However, some of the newly built infrastructure may have new features, such as the Øresund Bridge between Sweden and Denmark, or include some kind of charging, e.g. a new toll road. In those cases, re-using or updating an existing model may not be sufficient and the development of a new model to capture the induced behavioural patterns may be warranted.

- *Project organisation.* Usually when evaluating infrastructure it is good practice to have stakeholders within the project organisation.

- *Scope and type of model.* For all models that evaluate infrastructure, the geographical scale, time horizon, and detail of zoning should tie in with the actual planning context.

- *Choice of software/GIS.* This is no different than for other models. GIS can be useful to present the results to stakeholders.

- *Establish maintenance procedure.* Like other models, regularly updating and improvements are needed to meet the ongoing demand for forecasts.

- *Tendering.* Depending on the complexity required for the study, a tendering procedure may be required.
The table shows the models for infrastructure planning by mode and scope.

### Table 3-31: Transport models for infrastructure planning according to modes of transport included and passenger/freight

<table>
<thead>
<tr>
<th>modes</th>
<th>not known</th>
<th>Passenger</th>
<th>freight</th>
<th>both</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Rail</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>12</td>
<td>2</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>road/rail/iww</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>road/rail/sea</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>road/rail/air</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>road/rail/slow</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>road/rail/iww/sea</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>road/rail/iww/slow</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/sea/air</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6</strong></td>
<td><strong>30</strong></td>
<td><strong>22</strong></td>
<td><strong>9</strong></td>
<td><strong>67</strong></td>
</tr>
</tbody>
</table>

### 3.8.3 Model development

Models used to analyse infrastructure projects, in this case mostly road projects, depend on the geographical scale, detail and time horizon. Models used for road infrastructure planning range from simple route choice models to complex modelling at the regional or national level. Traditionally, many road projects have been evaluated based on route choice models and fixed matrices without considering induced or modal shifts. This does not take full account of the proposed new road project and will bias the assessment results. Therefore, models used to evaluate road projects should include demand modelling as well as route choice decisions, preferably in a logit-based framework.

Of course, congestion effects are core issues in the evaluation of road projects, and should always be considered in the model. In densely populated areas, intersection delays are also crucial in modelling car flows.

Today, the modelling of road infrastructure planning often forms a part of a more general passenger and freight transport model at different scales, e.g. national models in Sweden, the Netherlands, Germany, and the UK.

As can be seen in
Table 3-32 below, many models used for infrastructure planning currently exist in Europe according to the MDir.
Table 3-2: List of models from MDir that can be used for infrastructure planning

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport model Ile de France</td>
<td>U \ R</td>
<td>France</td>
<td>Prognos Goods Transport Forecast Model</td>
<td>N \ I</td>
<td>Switzerland</td>
</tr>
<tr>
<td>IVV-NRWF</td>
<td>N \ R</td>
<td>Germany</td>
<td>E3ME</td>
<td>N \ I</td>
<td>UK</td>
</tr>
<tr>
<td>Gravity Model for International Traffic</td>
<td>N \ I</td>
<td>Finland</td>
<td>Market share model</td>
<td>N \ I</td>
<td>UK</td>
</tr>
<tr>
<td>Birmingham Northern Relief Road</td>
<td>U \ R</td>
<td>UK</td>
<td>SAMGODS</td>
<td>N \ I</td>
<td>Finland</td>
</tr>
<tr>
<td>The Greater Thessaloniki Transportation Model</td>
<td>U \ R</td>
<td>Greece</td>
<td>CODE-TEN Corridor Assessment DSS</td>
<td>N \ I</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Passflow 2000</td>
<td>N \ R</td>
<td>Greece</td>
<td>Evaluation model concerning the freight transport corridor between Italy and Greece</td>
<td>NK</td>
<td>France</td>
</tr>
<tr>
<td>Bauconsult model</td>
<td>N \ I</td>
<td>Hungary</td>
<td>by the model owned by the Directorate of Public Works</td>
<td>NK</td>
<td>Greece</td>
</tr>
<tr>
<td>T-MESO</td>
<td>N \ R</td>
<td>Italy</td>
<td>RES-DYNAM</td>
<td>U \ R</td>
<td>France</td>
</tr>
<tr>
<td>ROADNET</td>
<td>U \ R</td>
<td>Italy</td>
<td>SAMPERS</td>
<td>N \ R</td>
<td>Sweden</td>
</tr>
<tr>
<td>National Danish Road Traffic Model</td>
<td>N \ R</td>
<td>Denmark</td>
<td>PLANET99</td>
<td>U \ R</td>
<td>Non European countries</td>
</tr>
<tr>
<td>Randstadmodel</td>
<td>U \ R</td>
<td>Netherlands</td>
<td>Toll road models for Santiago, Chile</td>
<td>U \ R</td>
<td>Non European countries</td>
</tr>
<tr>
<td>STEMM - Freight</td>
<td>I</td>
<td>Western Europe Partly</td>
<td>San Juan Strategic Traffic Model</td>
<td>U \ R</td>
<td>Non European countries</td>
</tr>
<tr>
<td>OEST France (passenger/freight models)</td>
<td>N \ R</td>
<td>France</td>
<td>Vega Baja-Manatí Land Use and Transportation Study</td>
<td>U \ R</td>
<td>Non European countries</td>
</tr>
<tr>
<td>Great Britain freight model</td>
<td>N \ R</td>
<td>UK</td>
<td>CAM mobility</td>
<td>U \ R</td>
<td>Non European countries</td>
</tr>
<tr>
<td>Sweden, SIKA</td>
<td>N \ R</td>
<td>Sweden</td>
<td>East Denmark Model (KRM)</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>Austrian passenger/freight models</td>
<td>N \ R</td>
<td>Austria</td>
<td>Analyse degli effetti sui flussi di traffico conseguenti alla chiusura del traforo del Monte Bianco (Analysis of the effects on traffic flows due to the closure of the Monte Bianco Tunnel)</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>LASER</td>
<td>NK</td>
<td>not known</td>
<td>Studio di fattibilita nuova linea ferroviaria di accesso sud alla galleria di valico del gottardo - Feasibility study of the new south access railway line to the</td>
<td>NK</td>
<td>not known</td>
</tr>
</tbody>
</table>

**MOTOS 102 of 139**
3.9 Pricing

3.9.1 Policy needs

The general increase in real income in recent years has resulted in more cars, longer trips, and fewer passengers per car in many European cities and countries. Many politicians have realised that using fiscal instruments to keep traffic at a reasonable level are useful, however, without a thorough understanding of whether this is also the best possible solution from a socio-economic point of view.

London has been successful in implementing a toll ring around the city centre, which has reduced the level of congestion by more than 30% inside the toll ring. The system has recently been updated with an extension to a wider area. Stockholm has recently finalised a...
full-scale experiment, which is expected to produce a significant social surplus, whilst Rome, Oslo, Trondheim and Bergen have already implemented tolling schemes.

At a national level, Germany (MAUT), Switzerland and Austria have introduced tolling systems for trucks, while pay motorways are widely used particularly in France, Italy and Spain. In Denmark and Norway, many road bridges and tunnels have been funded by tolls.

Accordingly, pricing is already a widely used policy instrument. In economics, pricing is often argued to be a more efficient tax than income tax. Many economists argue that the most efficient way of charging is to introduce a charge that is equal to the marginal costs a car imposes on society (in terms of increased congestion, pollution, accidents, noise, etc.).

What is less often discussed is the potential indirect impact of pricing on the economy in terms of, for example, the labour market and industrial competitiveness. The cost increase will have a dampening effect, but at the same time faster travel times will have a positive impact. Users with high value of time (business travellers, trucks, and high-income commuters) typically stand to benefit from this trade-off, while users with low value of time will suffer by having to change their travel behaviour, thus resulting in a negative user surplus.

Although many analyses of road pricing only focus on network effects, it may therefore be important to include a wider economic analysis.

Policy needs with respect to pricing are described in more detail in section 9.4.1 of part 3.

3.9.2 Organisation

- **Budget, Planning, Ambitions.** Pricing will have direct effects (to be modelled in an assignment model), demand effects (demand model) and derived economic effects (economic model). It is therefore important that a wide range of effects can be modelled. Depending on the design of the system, it may also be necessary to model both passenger and freight transport.

- **Project organisation.** Due to the inclusion of indirect network effects, economic experts may need to be included in the study team and steering group, with experts specialised in traffic assignment and demand modelling making up the core team.

- **Scope and type of model.** These will depend on the scale of the pricing system; urban pricing will require detailed modelling of commuting patterns and its impact on the labour market. A national system will require a greater focus on longer trips and regional economic effects.

- **Choice of software/GIS.** Dedicated traffic assignment software will be needed. The demand model may be quite complex, which will require flexible software. The economic model may be a Spatial Computable Equilibrium (SCGE) model, although this is a secondary effect compared to the direct network effects.
Establish maintenance procedure. Most likely, pricing models will be used to decide whether or not to introduce a particular system. This means that there is not the same need for maintenance as is the case with models used for, e.g., continuous planning purposes. The model can be used to adjust the prices in future years (although this can also be done by sequential smaller adjustments.

Tendering. The tendering procedure will not really be different from other models, except that it will require experts in the field of pricing and assignment modelling (beyond traditional specialists in demand modelling).

3.9.3 Model development
A proper pricing model should consist of the following elements;
1. Assignment model
2. Demand model
3. Economic model
4. Impact model

It is important that the Level of Services (LoS), e.g. travel times and travel costs, from the assignment are reflected in the demand model, and that changes in demand and LoS are reflected in the economic model. Typically, the impact model will use the output from the other models as input.

1. Assignment model
The assignment model describes route choices and congestion. Pricing may have two main behavioural impacts:
- Users with low value of time will reduce their travelling and change routes to avoid the charges. This is the main effect of pricing.
- Users with high value of time may take advantage of reduced travel times due to the main effect of pricing. This is a secondary effect.

This leads to the following main requirements for the assignment model:
- Ability to model the trade-off between time, length, congestion and charging
- Ability to model congestion
- Ability to distinguish between user groups, and preferably also between the preferences within groups.

Section 9.5 of part 3 describes the main recommendations for road transport assignment models, including how to meet the above requirements. It is generally recommended that a multi-class stochastic user equilibrium model be used, with utility functions that as a minimum include time, length, extra time due to congestion, and charging. Preferably, the error term should describe overlapping routes, and the stochastic coefficients should describe taste heterogeneity within each user group. With regard to pricing, it is recommended that the following user groups be explicitly included in the model:
- For short-distance models: commuters, shopping trips, and leisure trips
- Vacation trips (for long-distance transport only)
2. Demand model
It is important that the demand model should incorporate the LoS data from the assignment model, and if possible, have the same structure in terms of trip purposes. This should influence the 3 “traditional” steps in demand models:
1. Trip frequency
2. Destination choice
3. Mode choice

It should be noted, however, that many pricing systems have specific rush-hour charges, which will necessitate a time-of-day choice model. As pricing may change trip chains, time-of-day, activities, and length of activities, it is obvious that pricing is one of the areas which would benefit the most from an activity-based model, which will, however, require state-of-the-art modelling. For some strategic purposes, it may also be relevant to model the impact of pricing on car ownership. In section 13.2.5 of part 3 and section 4.5 of part 4 an example of a prototype of an activity-based model is described.

3. Economic model
Pricing will influence transport cost and commuting time, which in turn will have an impact on the labour market, such as working hours, and on manufacturing in general. For strategic purposes and analyses, it may therefore be relevant to include a link to an economic model; although, this is rarely done. One example, though, is the European TRANS-TOOLS model, which combines the CGEurope model and transport models.

4. Impact model
Pricing may have the following impacts:
- Consumer surplus (time savings) for users with a high value of time
- Consumer loss for users that change behaviour to avoid charging
- Producer surplus in public transport (due to more users within the existing supply system)
- Reduced tax distortion (since pricing may be considered a less distorting tax than income tax). This depends heavily on the assumptions used, as well as use of revenue
- Traffic safety impacts (typically, lower number of accidents)
- Reduced emissions
- Reduced local exposure to particle pollution
- Reduced energy use
- Reduced noise levels
- Reduced maintenance costs

The impacts must then be compared with the cost of establishing and running the pricing system.
3.10 Road Traffic Management

3.10.1 Policy needs

Today’s road traffic controllers need highly reliable and intuitive graphical user interfaces (GUIs) that enable real-time monitoring of traffic and on-screen interaction with data sources and signalling equipment. These GUIs must consolidate information, taking data from diverse sources -- sensors, cameras and databases, for example -- and display it in a graphical environment. The traffic controller needs to be able to spot potential congestion points and immediately take steps to prevent traffic jams from occurring.

Road traffic management delivers an important contribution to accessibility. Available roads will be used optimally when a proper road traffic management system is in place. Travellers will be able to make well-considered choices with respect to modes, departure time and route. New technological developments have led to new applications. For example:

In traffic management centres, traffic controllers monitor real-time traffic and can interfere in the network as and when necessary. It takes a great deal of expertise to understand the complex network effects of utilization measures. A region-based approach to utilization measures is a good base for further actions, including the co-ordinated development and activation of diversions in connection with road works, events and incidents. Also, forecasting models can be used in real-time traffic management. Using current information (counts), the model can provide a forecast for the near future so possible bottlenecks can be identified and, hopefully, by taking the right measure can be avoided. Based on a statistical analysis of data, patterns can be recognized to understand the network by using transport models. In this way, reliable predictions of traffic flows and travel times can be made for the present situation and near future.

Other examples of road traffic management include navigation systems and (dynamic) route planners on the Internet.

The transportation system is increasingly reaching the limits of its existing capacity due to the increasing demand for transportation caused by changes in activities, increasing prosperity and economic growth. For decades traffic signal control has been the most important traffic management measure, especially in urban areas. Traffic management systems have been deployed on the motorways for 25 years. In a wider context, traffic signal control and other traffic management systems form a part of the Intelligent Transportation System (ITS). Using ITS, the goal is to improve the transportation system by making it more effective, more efficient and safer.

Traditionally, traffic management is local. There is a local problem, which is resolved by putting in place a local traffic management measure, usually without considering the impact on the rest of the transportation system or other side effects. Also, in most cases, motorways and urban roads are operated and maintained by different road managers. In practice, they are only responsible for their own patch and there are no incentives for them to cooperate. Once this problem is recognised, a cooperation structure can be developed. Cooperation becomes even more urgent if one realises that the majority of delays suffered by road users occur on rural and urban roads rather than the motorway network. It was estimated that in
Several traffic control architectures have been developed to provide a structured description of the complex system of traffic and traffic management measures. They can be used to develop and implement a consistent and (politically) acceptable set of traffic management measures and construct the necessary technical and information infrastructure. Examples of traffic control architectures include the European KAREN Architecture, Dutch Traffic Management Architecture, US National Architecture, and Japanese HIDO Handbook.

A distinction can be made between on-line and off-line traffic management.

In on-line traffic management we want to know the exact details of present traffic volumes and speeds (continuously) on all roads. In the case of off-line policy evaluation, we want to gain a reliable picture of a representative selection in terms of time and space, but not necessarily in real time.

<table>
<thead>
<tr>
<th>Traffic models for road traffic management according to regional detail and passenger/freight</th>
<th>Regional detail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
<td>Urban / regional</td>
</tr>
<tr>
<td>Passenger not known / freight known</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>passenger</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>freight</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>both</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>13</td>
</tr>
</tbody>
</table>

3.10.2 Organisation
The following organisational issues are important when researching road traffic management:

- **Budget, Planning, Ambitions.** In most cases, road traffic management models are based on static models that are already available. The cost of constructing a dynamic management model is approximately 40% to 50% of the cost of constructing a static model.
- **Project organisation.** The project team involved in constructing a road traffic management model usually includes the road authority and/or traffic management control centre. Because the information generated by dynamic models is very complex, the regional authority should have specialist in-house expertise.
- **Scope and type of model.** These are determined by the policy issue to be addressed. In the majority of cases, a static model will be used as a basis for a macroscopic dynamic model. It is important to realise that validating a dynamic model is not as easy as in static modelling because of the complexity (dynamics) of the model system.
- **Choice of software/GIS.** Most transport modelling software has a dynamic modelling module as well as a static one. It is only logical to use the same software for both the static
and dynamic models. For reasons of calculation time, it is common practice to build a sub-model (sub-network and sub-matrix) from a static model.

- **Establish maintenance procedure.** Maintenance of a dynamic model depends on the maintenance of the static model, which is normally updated once every 2 to 5 years. It is recommended all changes in the network should be saved in a database annually. This will make it easier for the model to be updated after 2 to 5 years.

- **Tendering.** Who will construct the model? The development of dynamic road traffic management model is usually put out to tender. Usually 3 to 5 leading companies are invited to submit a proposal.

A lot of road traffic management measures are assessed with the help of a micro-simulation model. It would go beyond the purpose of this handbook to look at this issue in greater detail. However, road traffic management policy measures are increasingly dealt with on the strategic level. This means that “standard” transport models also need to be able to cope with policy measures of this kind. In practice, old-fashioned static models are not really suitable to address these questions. Instead, dynamic assignment models (see section 9.1.5.3 of part 3 are increasingly being used to deal with this kind of policy measures.

### Table 3-34: Transport models for road traffic management according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th>modes</th>
<th>not known</th>
<th>passenger</th>
<th>freight</th>
<th>both</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>not known</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Road</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Iww</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>road/rail/sea/air</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5</strong></td>
<td><strong>9</strong></td>
<td><strong>5</strong></td>
<td><strong>5</strong></td>
<td><strong>24</strong></td>
</tr>
</tbody>
</table>

#### 3.10.3 Model development

In practice, most dynamic assignment models are based on static models that are already available. Usually, the static model is used to construct a sub-model so that a dynamic model network remains, covering the entire study area within a specific region.

A number of extra attributes will have to be added to the network, such as saturation flows, number of lanes, speed at capacity, and the configuration of traffic junctions. This is another reason why it is advisable to use a sub-model, because gathering all this information for a large-scale network may well be too expensive.

In a static modal, an O-D matrix is usually determined for a one-hour or two-hour peak period. For dynamic modelling purposes, the O-D matrix is then divided into time slices of 5 to 15 minutes. The time profile for this process of constructing dynamic matrices can be derived from counts.
Data collection
Traffic management involves several data collection techniques. A distinction can be made between point information, route information, and area information:

- **Point information** can be gathered, for example, by detection loops, radar, laser, microwave or video. The data offers information about traffic flows and speeds at specific locations.
- **Route information** techniques include tracing vehicles by video or the advanced use of loops. This kind of data offers travel time information for specific routes.
- **Area information** includes floating car data collected by mobile phone or GPS. This data offers travel time information for (almost) all roads within a particular area (see section 5.8.3 of part 3).

HARS (The Alkmaar Control System)
Since 1999 the local, regional and national authorities have worked together to improve traffic performance in and around the town of Alkmaar, The Netherlands. Route information panels have been put in place, a parking information system has been developed, and the regulation of traffic lights on the ring have been improved. All of these measures have been integrated into a single regional traffic management system called HARS. All dynamic measures taken at and around the Alkmaar ring road are coordinated by this one regional traffic management system.

The system works both top-down and bottom-up:

**Top-down:** The approach to all known traffic problems was defined beforehand by traffic regulation scenario experts. These scenarios operate fully automatically.

**Bottom-up:** The HARS system controls traffic independently on the basis of monitoring data. This allows traffic flows to better distributed across the network. If there is too much traffic in one part of the network, HARS can direct traffic to another part that has some capacity left.

A best practice example of road traffic management is the toll study conducted in Eindhoven, The Netherlands (see section 13.4.3 of part 3 and section 6.3 of part 4). In this study, several toll scenarios were defined to investigate what impact the introduction of toll on new infrastructure would have on revenues and the secondary network. Use was made of a macroscopic dynamic assignment model.
Table 3-35: List of models from MDir that can be used for traffic management

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widening Traffic Model</td>
<td>U \ R</td>
<td>UK</td>
<td>POLYDROM</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>Birmingham Northern Relief Road</td>
<td>U \ R</td>
<td>UK</td>
<td>Flexible Simulation Study Tool (FLEXSYT-II)</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Performance Indicator Package</td>
<td>U \ R</td>
<td>Italy</td>
<td>SIMOE</td>
<td>U \ R</td>
<td>France</td>
</tr>
<tr>
<td>TELEMACO</td>
<td>U \ R</td>
<td>Italy</td>
<td>METACOR</td>
<td>U \ R</td>
<td>France</td>
</tr>
<tr>
<td>North Western Europe Model</td>
<td>I</td>
<td>Western Europe</td>
<td>SIMTRAP</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>VP-WEG</td>
<td>N \ R</td>
<td>Netherlands</td>
<td>VISSIM</td>
<td>U \ R</td>
<td>France</td>
</tr>
<tr>
<td>PAWN</td>
<td>N \ R</td>
<td>Netherlands</td>
<td>CROSSIG</td>
<td>NK</td>
<td>France</td>
</tr>
<tr>
<td>ESIM</td>
<td>U \ R</td>
<td>Netherlands</td>
<td>Passenger Transport Model for Helsinki Metropolitan Area</td>
<td>U \ R</td>
<td>Finland</td>
</tr>
<tr>
<td>Short-term Traffic Model (STM)</td>
<td>U \ R</td>
<td>Netherlands</td>
<td>Amsterdam Model</td>
<td>U \ R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>East West traffic model of Denmark</td>
<td>N \ I</td>
<td>Denmark</td>
<td>Stockholm model</td>
<td>U \ R</td>
<td>Sweden</td>
</tr>
<tr>
<td>TELESCOPEAGE</td>
<td>NK</td>
<td>Netherlands</td>
<td>Copenhagen model</td>
<td>U \ R</td>
<td>Denmark</td>
</tr>
<tr>
<td>DAVIS</td>
<td>NK</td>
<td>not known</td>
<td>INDY</td>
<td>N \ R</td>
<td>Netherlands</td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

3.11 Urban Public Transport planning

3.11.1 Policy needs
Public transport comes in a variety of modes, e.g. railways, buses, dial-a-ride systems, taxis, human services transport, and ride sharing. This section looks at the traditional modes of public transport like rail and bus systems.

Historically, the promotion of urban public transport has been seen as a tool to improve urban mobility. Public transport caters to fundamental transport needs and allows people with no access to cars to move out of downtown areas and still have access to workplace and shopping areas. In many European cities, a large part of residents still have no access to a car or, indeed a driving licence, and therefore rely on public transport for many trip purposes.

A well-organised and efficient public transport system may reduce negative externalities such as air pollution, noise pollution, safety, and congestion. In the White Paper on ‘Good Urban Practice’ the Commission promotes more and better public transport in urban areas. As traffic and urban congestion increase, the provision of new urban road infrastructure seems increasingly difficult to achieve without incurring substantial costs and making a considerable impact on social life in the city. Public transport improvements combined with other instruments like pricing policy may will result in a modal shift from car to public transport and thus support sustainable mobility in urban areas.
An efficient, well-planned and integrated public transport system, based on a mix of different public transport modes exploiting their individual strengths, could increase ridership while at the same time reducing costs. The provision of public transport should reflect the demand pattern. For instance, extensive travel to commercial or industrial areas can often efficiently be covered by public transport services. Coordination of departure times and line services will reduce travel times for passengers and increase revenues. Users rate punctuality, reliability, and dependability of a public transport system as very important features. As life becomes busier, it is essential that reliable public transport services are in place. An example of a rail punctuality model is described in section 13.4.1 of part 3 and section 6.1 of part 4.

A combination of land use planning and public transport planning is often seen as an efficient way to support sustainable mobility in urban areas. Past experience has shown that if newly developed areas are provided with good public transport, the cost-usage ratio is low. The development of a new town near Copenhagen (Ørestad), combined with new underground services, is an example of integrated land use and transport planning.

In suburban areas, in particular, park-and-ride facilities are becoming increasingly popular. Although the experiences with park-and-ride systems are somewhat doubtful, it is potentially a good way of combining private transport modes with public transport services.

In practice, fare policies are often applied to increase revenues or patronage. Today, a variety of instruments are available and in the future even more may emerge, such as smart cards to pay for public transport. This will allow the introduction of flexible and very specific policies to push demand in the direction desired by policymakers.

Another concern in relation to public transport planning is cost reduction. For instance, operational efficiency could be improved by reducing dwell times, increasing capacity usage, reducing car fleets, and reducing the number of empty vehicles let idle.

The next table shows that 27 models are particularly useful for urban public transport planning.
Table 3-36: Transport models for urban transport planning according to regional detail and passenger/freight

<table>
<thead>
<tr>
<th>Regional detail</th>
<th>not known</th>
<th>Urban / regional</th>
<th>National models / regional</th>
<th>national models incl. international</th>
<th>internation al models</th>
</tr>
</thead>
<tbody>
<tr>
<td>modes</td>
<td>not known</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Road</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rail</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>road/rail/sea</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/air</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>road/rail/slow</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail/se a/air</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>12</td>
<td>8</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

a 1st Keyword = public transport planning

3.11.2 Organisation
The following organisational issues are important when developing a transport model for urban public transport planning:

- **Budget, Planning, Ambitions**: public transport planning is usually part of urban transport planning, when regional or urban models are used to study the changes in travel demand. Because the interaction between and substitution of transport modes and urban travel patterns are very complex, urban public transport modelling requires professional skills and data collections and, hence, a rather considerable budget.
- **Project organisation**. When evaluating urban public transport, it is usually good practice to include stakeholders in the project organisation.
- **Scope and type of model**. To capture the complexity of urban travel, state-of-practice models should be used which include all modes along with modal shift effects and route choice models which take account of congestion. The operation of urban public transport (supply side) can be evaluated by using advanced timetable-based route choice models.
- **Choice of software/GIS**. This is no different than for other models. GIS can be useful to present the results to stakeholders.
- **Establish maintenance procedure**. A regular updating and improvement procedure should be put in place in order to track changes in demand patterns, make forecasts more reliable, and take advantage of new data and model developments.
- **Tendering**. The development of an urban transport model usually requires a tendering procedure and an evaluation team to monitor and validate the model.

The next table shows the models for urban public transport planning by modes and scope.
Table 3-37: Transport models for urban public transport planning according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th>modes</th>
<th>not known</th>
<th>passenger</th>
<th>both</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Rail</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>9</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>road/rail/sea</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/air</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>road/rail/slow</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>road/rail/sea/air</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1</strong></td>
<td><strong>25</strong></td>
<td><strong>1</strong></td>
<td><strong>27</strong></td>
</tr>
</tbody>
</table>

a 1st Keyword = public transport planning

### 3.11.3 Model development

Urban public transport planning forms a part of urban transport planning. Accordingly, urban public transport modelling cannot usually be seen in isolation from other modes of transport. In the context of urban transport modelling, we need to consider all modes of transport (walking, cycling, car and public transport). In the Northern European cities, in particular, cycling accounts for a large part of urban travel and in that sense competes with public transport. Longer walking trips also compete with public transport. For instance, the OTM model used in public transport studies in Copenhagen (see section 13.2.4 of part 3 and section 4.4 of part 4) has shown that to neglect walking trips will bias the results when looking at changes in public transport services. An other example of a public urban transport model is described in section 13.5.3 of part 3 and section 7.3 of part 4.

The modelling scale should be either regional or urban, because larger-scale models are incapable of modelling the details required to assess urban transport policies. The state-of-practice option would be to use a nested tour-based logit model for demand modelling, including models for travel frequency, trip distribution, and mode choice broken down by trip purpose. In sections 13.2.4 and 13.2.6 of part 3 and sections 4.4 and 4.6 of part 4 examples of a tour-based model are described. Induced traffic should be included in trip generation so as to reflect the effects of, for instance, public transport improvements. It is also important to separate out car passengers from car drivers in the mode choice model, because car passengers are more sensitive to changes in public transport than car drivers.

Public transport usage is influenced by the severity of urban road congestion, hence it is vital to include congestion effects and intersection delays in the car assignment model. We need to include light goods vehicles in the assignment to model traffic congestion.

Different route choice models may be considered for public transport, depending on the objectives of the model. In strategic studies, aggregated procedures may meet the requirements of accuracy, whereas timetable-based route choice models may be needed for more detailed assessment studies and the evaluation of passenger delays.
Urban transport models, or elements of urban transport models are not easily transferred from one city to another, because networks, land use, social and political issues, travel behaviour, etc., may vary to a large extent. It is therefore recommended that data be collected and a model developed for the specific purposes of each individual area.

Table 3-38 shows a number of examples of European models.

### Table 3-38: List of models from MDir that can be used for urban public transport planning

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alsace Model</td>
<td>N \ I</td>
<td>France</td>
<td>SIMPT (Sistema Informativo per il Monitoraggio e la Planificazione dei Trasporti)</td>
<td>N \ R</td>
<td>Italy</td>
</tr>
<tr>
<td>SIMPT (Sistema Informativo per il Monitoraggio e la Planificazione dei Trasporti)</td>
<td>N \ R</td>
<td>Italy</td>
<td>MATISSE-INTRAPLAN TRAFFIC AND PROFITABILITY FOR A WESTERN EUROPEAN HIGH-SPEED TRAIN NETWORK MODEL</td>
<td>N \ R</td>
<td>Italy</td>
</tr>
<tr>
<td>Langfrist projection model</td>
<td>N \ R</td>
<td>Germany</td>
<td>ANTONIN</td>
<td>U \ R</td>
<td>France</td>
</tr>
<tr>
<td>National Passenger Traffic Demand Model</td>
<td>N \ R</td>
<td>Finland</td>
<td>VISMUS 7.0</td>
<td>U \ R</td>
<td>Sweden</td>
</tr>
<tr>
<td>HSL Substitution Model</td>
<td>I \ ds</td>
<td>France</td>
<td>Economic studies for the regional railways in Marseille metropolitan area (France)</td>
<td>U \ R</td>
<td>France</td>
</tr>
<tr>
<td>Railplan</td>
<td>U \ R</td>
<td>UK</td>
<td>Demand study for guided bus system in Santiago, Chile</td>
<td>U \ R</td>
<td>Non European countries</td>
</tr>
<tr>
<td>Passenger Train Model</td>
<td>U \ R</td>
<td>UK</td>
<td>Ørestad model (OTM)</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>SAX++.NET</td>
<td>I \ R</td>
<td>Belgium</td>
<td>Hungarian Urban models developed KTI public company</td>
<td>U \ R</td>
<td>Hungary</td>
</tr>
<tr>
<td>Model for Province of Antwerpen (passenger model)</td>
<td>N \ R</td>
<td>Austria</td>
<td>High Speed Trains / 10-Year Highway Plan</td>
<td>N \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>Bavaria Reference Model</td>
<td>I \ R</td>
<td>Italy</td>
<td>High Speed Trains / 10-Year Highway Plan</td>
<td>N \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>SOUTH GERMANY</td>
<td>I \ R</td>
<td>Belgium</td>
<td>High Speed Trains / 10-Year Highway Plan</td>
<td>N \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>JoinGNET</td>
<td>I \ R</td>
<td>Italy</td>
<td>KOM-ZB</td>
<td>U \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>TELEMACO</td>
<td>I \ R</td>
<td>Italy</td>
<td>City’s trip distribution</td>
<td>U \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>SAS</td>
<td>N \ R</td>
<td>Italy</td>
<td>PT Market organization</td>
<td>N \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>High Speed Trains / 10-Year Highway Plan</td>
<td>N \ R</td>
<td>Finland</td>
<td>PT Ticket</td>
<td>U \ R</td>
<td>Poland</td>
</tr>
<tr>
<td>Bundesland OberOsterreich</td>
<td>I \ R</td>
<td>Austria</td>
<td>PT Ticket</td>
<td>U \ R</td>
<td>Poland</td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

### 3.12 Rail transport planning

#### 3.12.1 Policy needs

Rail transport in the European Union is undergoing fundamental change as a result of the liberalisation process that is underway. In this new environment, appropriate planning tools are an important aid to the companies involved.
In the railway sector, strategic decisions (as opposed to tactical or operational decisions) can be defined as long-term decisions that involve large investments and have a significant impact on the system configuration. The planning of a rail freight system is complex and requires using techniques to assist in the various different planning activities, such as long-term demand forecasting; analysis and selection of technological alternatives; assessment of new infrastructure requirements; and definition of general operational policy.

The challenge is to design the most effective rail transport network in terms of layout and operational policy, one that will accommodate expected market developments. As some authors have pointed out, the design of a transport system is often not undertaken as an overall integrated process. It is usually fragmented. For example, infrastructure and operational changes are often considered separately and local projects assessed without taking into account the implications for the network as a whole.

That said, perhaps as a consequence of increased competitive pressures, new planning methodologies are being developed that include network models by way of analysis tools. The great advantage of a network model is that it enables a full analysis of the various components of a rail network and their interaction. Network models vary greatly, depending on the type of decision to be assessed or the techniques used to develop the model. As to the latter factor, network models can be divided into analytical and simulation models. The models proposed most frequently in the literature are analytical and address tactical decisions. Schedule-based models and simulation models have, however, gained a foothold in the last 5 to 10 years, and are now used in several applied studies and models.

At the operational level, simulation models are more widely used for operational planning purposes, e.g. time-tabling, defining stopping patterns, and choosing rolling stock. Due to capacity dependencies and the greater focus on punctuality, operational models are increasingly being integrated into tactical and even strategic models.

In sections 13.5.1 and 13.6.2 of part 3 and sections 7.1 and 8.2 of part 4 examples rail transport models are described.

3.12.2 Organisation

- **Budget, Planning, Ambitions.** Rail transport models are complex and typically require some effort and a reasonably sized budget. Except in the case of very strategic decisions (e.g. the construction of a new high-speed rail line), models can be used continuously for planning purposes. The model should reflect the decision context, that is to say, a timetable-based assignment model should be used if the model is used for timetabling.
- **Project organisation.** If the model is used continuously for planning purposes, it is important to set up a permanent organisation led by the railway company or planning authority, while some of the model development will most likely require specialists from consulting firms and/or universities.
- **Scope and type of model.** In all cases, rail transport models will require assignment modelling. Whilst a frequency-based approach may be sufficient for strategic issues, a
timetable-based approach is recommended for tactical and operational purposes. Dependent on the study, demand models may be less refined. Only in very strategic planning studies, links to (regional) economic models will be relevant.

- **Choice of software/GIS.** Dedicated traffic assignment software for public transport will be needed; the demand model may use standard software. If reliability is an issue, specific rail simulation software may be needed as well.
- **Establish maintenance procedure.** As rail transport models are often used continuously for planning purposes, it is important that a permanent organisation is set up to take responsibility of maintenance procedures.
- **Tendering.** The tendering procedure is not really different from other models, except that it will require experts in the fields of public transport assignment and the railway sector).

### 3.12.3 Model development

A proper pricing model should consist of the following elements;
1. Assignment model
2. Rail simulation model
3. Demand model

It is important that the Level of Services (LoS), e.g. travel times and travel costs, generated by the assignment should be reflected in the demand model.

#### Assignment model

Two main approaches exists for public transport assignment; frequency-based models (see section 9.7.4 of part 3) and timetable-based models (section 9.7.5 of part 3). Because there are fewer requirements for the network data, frequency-based models may be used for strategic studies, while tactical and operational models will gain significant strength if a timetable-based (schedule-based) approach is adopted. Several standard software package are available in this regard.

Key requirements for schedule-based models include their ability:
- to model the trade-off between different sub-modes (walking, bicycle, bus, tram, light rail, underground, and train), time components (frequency, waiting time, transfer time, in-vehicle time), comfort (e.g. seat availability), and costs (see section 9.7.3 of part 3). The more advanced models use utility functions to describe the preferences and random coefficients to describe taste heterogeneity.
- to describe overlapping routes (the structure of the so-called error term)
- to model the timetables and transfers

#### Rail simulation model

Punctuality is an important issue in some of the more advanced models and studies (see section 9.6.2 of part 3). These require improved route choice models and links to specific rail simulation models. Section 9.7.5.3 of part 3 describes in further detail how reliability can be modelled within a schedule-based model, while section 9.6.2 of part 3 provides a brief introduction to rail simulation models.
Demand model
For operational and tactical issues, it may not be necessary to construct a highly advanced demand model. This would be more relevant for strategic models. The three “traditional” steps in demand modelling will usually be sufficient. They are:
1. Trip frequency
2. Destination choice
3. Mode choice

3.13 Intermodal solutions

3.13.1 Policy needs
Intermodal transport refers to a change between modes on a trip from origin to destination. This can occur in both passenger and freight transport. Intermodal transport is sometimes also associated with the transportation of standard load units (SLU), such as containers. The European Commission’s objective with regard to freight transport is to strengthen intermodal transport by using more environmentally friendly and less congested modes. This objective has a long history. As part of its proposed strategy, the European Commission wishes to remove the obstacles to the generalised use of intermodal transport by developing of infrastructure networks and trans-European transport nodes (COM(97) 243). More specifically, the Communication proposes the following measures:

Integrated infrastructure and transport means:
- Intensify intermodal design of the trans-European transport networks
- Enhance design and functions of intermodal transfer points
- Harmonise standards for transport means

Interoperable and interconnected operations means:
- Integration of freight freeways in an intermodal context
- Development of common charging and pricing principles
- Harmonise competition rules and state aid regimes on an intermodal basis

Mode-independent services and regulations means:
- Harmonisation and standardisation of procedures and EDI
- Intermodal liability
- Research and demonstration
- Benchmarking
- Intermodal statistics

The objective is to develop a framework for the optimal integration of different modes so as to enable an efficient and cost-effective use of the transport system through seamless, customer-orientated door-to-door services, whilst favouring competition between transport operators.

The European Union has been promoting intermodality for years. Programmes like PACT have helped intermodal operators develop new services and are aimed at strengthening the market. In some European countries, combined transport is heavily subsidized. After years of
significant growth rates in intermodal transport, a number of problems have led to stagnation, particularly as a result of the deregulation of the railway industry. The efforts put in by the industry in the 1990s to develop new and cost-efficient transhipment technologies have led to (theoretically) powerful technologies and several pilot sites. Terminal operators, however, still went on to rely on conventional techniques. Previous research and development activities have identified technical and organisational solutions that can be applied to strengthen intermodality. The key question was where these findings should be put in practice (in what parts of the networks, nodes, and regions). Consequently, an in-depth analysis of the state of transport infrastructure, organisation and operation and intermodal services was essential to identify an intermodal network.

Decision No. 1692/96/EC sets out Community guidelines for the development of a trans-European transport network. These criteria remain valid within the multilateral process of the overall Pre-Accession Strategy. It underpins the principles for interoperability of modes of transport and encourages intermodality between modes. It also outlines the scope of the network and the characteristics of its components.

Implementing a European intermodal transport network requires the coordinated development of a transport policy on a European, national and regional level. To achieve an interoperable European network and prevent a patchwork of national infrastructures and practices from arising, it will be necessary to make plans at a European level. To design this multi-modal network, a methodology needs to be defined to design a network taking into account existing conditions, the European Union’s needs, environmental considerations, etc., and using criteria derived from national socio-economic expectations.

The following reasons justify why the objectives will be more efficiently addressed at the European level rather than at a national/ regional/ private level:

- **European interest in enlargement**
  In terms of the EU enlargement process and the accession countries, there is a significant gap in development of the two sides. There are also many other differences their transport systems, which need to be developed and upgraded in order to have a multi-modal transport infrastructure in place on the Continent.

- **A Pan-European strategy on infrastructure (networks and nodes)**
  Regarding transport infrastructure development, the European Union has recognised the need for a network approach. An integrated multi-modal approach should be adopted with regard to the design of future traffic, based on existing transport parameters.

- **Intermodality**
  Tools need to be available to analyse the framework for implementation of an intermodal network and define an adequate system of intermodal, customer-oriented and door-to-door services.

- **The single transport market - Harmonisation of regulation and competition rules**
  Standards for means of transport should be harmonised and interoperable and interconnected operation should be developed on an intermodal basis.
The organisation of intermodal transport is a complex issue; there are multiple actors, all with their own interests, and there is more need for technical and communication interfaces. Even if a sufficient capacity network is established, intermodal transport chains will require a higher level of standardisation than unimodal transport.

Although on the basis of the mid-term assessment of the White Paper, the European Commission has decided to shift its focus from the promotion of intermodal transport to the concept of co-modality, the underlying principles remain largely the same. The main difference is that co-modality takes into account not only the development of intermodal transport, but also the development of individual modes.

### Table 3-39: Transport models for intermodal solutions according to regional detail and passenger/freight

<table>
<thead>
<tr>
<th>Regional detail</th>
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<td></td>
<td></td>
</tr>
<tr>
<td>Passenger not known</td>
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</tr>
<tr>
<td>Passenger known</td>
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</tr>
<tr>
<td>Passenger passenger</td>
<td>0</td>
</tr>
<tr>
<td>Passenger freight</td>
<td>0</td>
</tr>
<tr>
<td>Passenger both</td>
<td>0</td>
</tr>
<tr>
<td>Freight known</td>
<td>2</td>
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<tr>
<td>Freight passenger</td>
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<tr>
<td>Freight freight</td>
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</tr>
<tr>
<td>Freight both</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
</tr>
</tbody>
</table>

#### 3.13.2 Organisation

In developing the model, an integrated approach should be taken to the issues to be addressed. For the isolated investigation of infrastructural bottlenecks, European and national framework conditions, and current demand for intermodal services cannot offer economically, socially and environmentally sustainable solutions.

An integrated approach should consist of the following elements:
- Identification of requirements for intermodal transport (operational framework);
- Survey of status quo with regard to intermodal transport, organisation and operations;
- Assessment of status quo;
- Definition of network scenarios, assignment and investment requirements;
- Setting up a framework to implement a proper quality intermodal Pan-European network.

Three categories of indicators can be considered for the work:
- technical performance indicators;
- market determinants; and
- parameters for regulatory framework conditions.

Whereas technical performance can be assessed by benchmarking, the market determinants and framework conditions can be assessed by a SWOT analysis. Input data has to be gathered from available sources, such as research results and statistics and national research in the countries concerned.
To forecast traffic demand, assumptions must be made about the future economic structure and output volumes. There will necessarily entail a high level of uncertainty. Traffic forecasts are, for example, often used by the private sector to select arguments in favour of certain infrastructural measures, emphasising the necessity of adding capacity to and improving the quality of the networks, even if less costly organisational measures would help eliminate or reduce the bottleneck. On the other hand, financial funds for excessive infrastructural rehabilitation and construction are limited. Because demand forecasts will be made for the forecast year, there has to be a realistic view of the infrastructural measures already proposed and which can be expected to be completed and operational by the forecast year. The definition of the assumed components of this network base scenario is crucial in order to identify additional infrastructural and organisational measures. As experience with different projects has shown, it is essential that all those involved in the project reach a consensus on the definition of the network base scenario and demand base scenario. A workshop dedicated to this issue is often useful to approach the issue.

Table 3-40: Transport models for intermodal solutions according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th></th>
<th>passenger/freight</th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>passenger</td>
<td>freight</td>
<td>both</td>
<td>Total</td>
<td></td>
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<td>modes</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>road/rail</td>
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<td>0</td>
<td>0</td>
<td>2</td>
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<td>1</td>
<td>0</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

3.13.3 Model development

Broadly speaking, there are two different approaches to model this issue. The first one is to start off with building a base-year matrix to describe the intermodal transport flow. Next, the base year is used to make a forecast using a pivot point method:
1. Determine the base year potential based on logistical characteristics;
2. Calibrate the model on the basis of fragmented available data;
3. Make a forecast of future transport flows (e.g. by trade model and modal-split model);
4. Forecast the percentage intermodal by combining a pivot point method and potential determination method on the basis of the projected transport flows.

The second approach is to focus only on the forecast year:
1. Make a forecast of future transport flows (e.g. by trade model and modal-split model);
2. Determine the future potential on the basis of logistical characteristics;
3. Determine the share of intermodal transport that can realistically be obtained.

The advantage of the second method is that it is faster and less expensive. The downside is that it cannot be calibrated on the basis of observed information.

Because there are not many models relating to this issue, an example will be given below from the INTERMODA project, where the INTERMODA model was constructed on the basis of the NEAC model. The purpose of the INTERMODA model is to estimate future intermodal transport demand within and in relation to the CEECs. Different methods have
been applied to maritime and non-maritime transport flows. Both methods are described for both scenarios.

The intermodal model for non-maritime flows is based on the IQ and EUFRANET projects. In these projects, the potential intermodal transport is determined for the current situation in Western Europe. The intermodal model used in the INTERMODA project uses criteria comparable to those used in the aforementioned projects. The intermodal model determines future potential intermodal flows by applying criteria to future total transport flows. Specific thresholds for criteria such as commodity type, transport distance, transport volume and market share are applied, given the assumptions in the reference scenario and alternative scenario. In general, the relationship between the aforementioned criteria and intermodal transport is as follows:

- Commodity types: intermodal transport appears to have a higher share of, for example, foodstuffs, chemical products, and general cargo;

- Transport distance: the potential of intermodal transport lies primarily in long-distance relations. For short/distance transport, the transhipment and pre- and end-haulage activities at terminals make intermodal transport less competitive in comparison to road transport. For longer transport distances, these activities have (relatively) less influence on transport times and tariffs;

- Transport volume: to ensure profitability, a minimum level of transport volume is needed. The volume must guarantee a sufficient occupation rate of the transport unit (train, barge or vessel) in order to cover the high share of fixed costs and to make several departures per week possible;

- Market share: dependent on the conditions for intermodal transport, the market shares of intermodal transport in Western Europe differ between O-D relations. Under normal conditions, the market share is relatively low. Under improved conditions for intermodal transport, the market share is higher.

The intermodal model for maritime flows uses information about the current situation in Western Europe and applies this information to the transport flows in the CEECs in order to determine the potential intermodal flows.

Besides the NEAC model that was adapted for intermodal analysis, there are few other models that capture intermodality. In most cases, data is about complete chains of transport is difficult to obtain. A few data sources are available on the basis of which to estimate and calibrate models.
Table 3-41: List of models from MDir that can be used for intermodal solutions

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMBI FEEDER MODEL</td>
<td>N \ I</td>
<td>Denmark</td>
<td>Mathematical model for Intermodal Transport Choice</td>
<td>NK</td>
<td>known</td>
</tr>
<tr>
<td>LOGIQ Decision Support System for intermodal transport</td>
<td>NK</td>
<td>known</td>
<td></td>
<td>NK</td>
<td>known</td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

3.14 Project Impact Assessment

3.14.1 Policy needs

In the last decade there has been an increased focus on socio-economic impact assessments of significant infrastructure projects within the road haulage industry. There has also been an ongoing demand for environmental impact assessments due to the heightened debate about the environmental impact of road traffic. This has, in turn, led to stricter requirements being placed on socio-economic assessment methods. Decision-makers need to have an overview of all possible consequences of a specific project and/or policy decision. An example of such an overview is given in Figure 3-7.

Transport models provide information about changes in transport due to changes in, for example, the infrastructure. It is not possible to say whether or not a particular change is beneficial simply on the basis of the outputs of a transport model. It is also difficult to assess the benefits and costs of transport investments.

A socio-economic assessment is meant to provide a comprehensive analysis of the profitability of a project; however, there are always considerable uncertainties associated with such analyses. It is important therefore that the focus of the study encompasses more than mere numbers, such as net present value or the internal rate of return. Crucially, the analysis should also identify the factors that are critical to the outcome of the profitability evaluation. Another important element of a good quality socio-economic assessment is that it must provide a systematic and transparent account of the project’s benefits and costs, which will contribute to the openness of the decision-making process.
Figure 3-7: Example of a comprehensive overview of all impacts

An economic assessment can be conducted using one or more of approaches (see section 11.1 of part 3). Those most frequently used include:

- **Cost-Benefit Analysis (CBA)** A technique designed to determine the feasibility of a project or plan by quantifying its costs and benefits (see section 11.1.1 of part 3);
- **Multi-Criteria Analysis (MCA)**, which uses weights based on, for example, the decision-makers' ranking of different criteria. Different projects will be ranked according to these criteria (see section 11.1.2 of part 3); and
- **Multi-dimensional Comparison (MDC)**, which defines each impact in financial terms, quantitative terms or qualitative terms according to well-defined, systematic principles.

In fact, an MDC is a precondition for both a CBA and MCA. A CBA can be regarded as a special type of MCA that applies empirical appraisals to all impacts. Conversely, an MCA always involves an implicit appraisal of all impacts, insofar as one of the impacts is calculated in monetary units. The distinction between a CBA and MCA is a little vague; in most countries, project assessments are conducted using a combination of all three methods (see also Figure 3-8).
A given overall assessment method can be characterized by its placement within the triangle. Assessment methods are placed higher in the figure proportionate to how often the weighting is used, or lower the less often the weighting takes place.

In practice, a cost-benefit analysis is used the most when dealing with infrastructure investment decisions. If more general policy questions are to be dealt with, a multi-criteria analysis is more commonly used. It is important to note that while the output of a transport model is important, other aspects are at least as important. This means that good arguments are need to justify the Value Of Times that are being used, as well as for other impacts if they are monetarised (e.g. traffic safety, CO₂, air quality). A specific aspect, especially in the case of a CBA, is that the results need to be presented for a whole year. The assumption here is that the outcome from the transport model, an average working day, can be easily transferred into whole year figures. The assumptions made here always need to be properly checked.

**Table 3-42: Transport models for project impact assessment according to regional detail and passenger/freight**

<table>
<thead>
<tr>
<th></th>
<th>Regional detail</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
<td>Urban / regional</td>
<td>national models / regional</td>
<td>national models incl. international</td>
<td>international models</td>
</tr>
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<td>Passenger / freight</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>known passenger</td>
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<td>1</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>known freight</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>both</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td><strong>1</strong></td>
<td><strong>3</strong></td>
<td><strong>0</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>
3.14.2 Organisation

The following organisational issues are important when developing a tool to conduct a project impact assessment:

- **Budget, Planning, Ambitions.** A project assessment is not something which can be done in a few days after running the transport model. It is an independent activity and needs a budget and attention accordingly. The amount of the budget will depend on the scope of the project impact assessment. If all kinds of macro- and meso-economic effects are to be taken into account, the budget may well exceed the costs of the transport demand forecast.

- **Project organisation.** In most cases, a project impact assessment is done after the calculations have been made using the transport model. That is only logical, except that there is one complication. During the project assessment it often happens that new insights occur which lead to changes in a particular project alternative. This will also automatically lead to new forecasts having to be made using the transport model. The project organisation should be aware of this iterative process. To assume that it is a sequential process is true when one looks at the calculations, but the decision-making process is much more iterative.

- **Scope and type of model.** These are determined by the policy issue to be addressed. The first question which arises is what macro-economic effects are to be assessed. If the assessment is to look at a wide variety of macro-economic effects, the impacts will have to be assessed for a large (national) area. This will be the case, for example, if the project involves a large infrastructure investment (e.g. a new highway). If, however, the decision is between several trajectories of a specific motorway, than a more simple approach can be followed (see section 10.1 of part 3).

- **Choice of software/GIS.** Most project assessment techniques do not really require specific software. A simple spreadsheet application may do the trick. However, specific MCA and CBA software is available, such as TUBA, COBA, and QUADRO.

- **Establish maintenance procedure.** In this case, a great deal of attention will have to be given to transparency. This require proper documentation of the assumptions underlying the project assessment. These include items like Value Of Times or other monetary values (e.g. traffic safety, CO₂, air quality).

- **Tendering, who will build the model.** Project assessments are usually conducted by specialised consultants. Large engineering firms will be able do both the transport demand forecasting and project impact assessment. There are benefits and downsides to both approaches. Either way, it should be clear and transparent how a proper interfacing between the transport model output and project impact assessment input is guaranteed.
Table 3.43: Transport models for project impact assessment according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th>modes</th>
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<th>passenger</th>
<th>freight</th>
<th>both</th>
<th>Total</th>
</tr>
</thead>
<tbody>
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<td>road</td>
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<td>air</td>
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<td>1</td>
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<td>2</td>
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<td>9</td>
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</tbody>
</table>

3.14.3 Model development

The project impact assessment will be the basis of the policy decisions. A good quality project impact assessment can help decision-makers form an opinion. This will, however, require maximum transparency. Policymakers are not particularly fond of a black box approach. It is, therefore, necessary to know the conditions and assumptions underlying the assessment. Major factors which may lead to an incorrect interpretation of comparisons are:

- measure used: benefit/cost ratios of different kinds or rate of return measure;
- evaluation period;
- discount rate;
- traffic forecast; and
- economic value of different parameters.

Last but not least it should be realised that the outcomes of the project impact assessment involve all sorts of uncertainties (see section 10.1.2.3 of part 3). The aim of a traditional risk analysis is to hand the decision-maker a means to look at the whole of future outcomes. The advantage of using a risk analysis is that it is possible to differentiate between the features of the risk information in terms of outcome criteria such as net present value (NPV), internal rate of return (IRR), or benefit/cost ratio (B-C rate) by probability distributions.

Table 3.44: List of models from MDir that can be used for project impact assessment

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATISSE</td>
<td>I</td>
<td>France</td>
<td>Model for the private investments</td>
<td>NK</td>
<td>Greece</td>
</tr>
<tr>
<td>Brenner model</td>
<td>I</td>
<td>Austria</td>
<td>Feasibility for the Freight Village of Kilkis</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>Urban and Regional Planning Support Model</td>
<td>N \ R</td>
<td>Portugal</td>
<td>PROFIT-Model</td>
<td>NK</td>
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<tr>
<td>SIET</td>
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<td>Spain</td>
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<tr>
<td>WFTM</td>
<td>N \ R</td>
<td>Belgium</td>
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<td></td>
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</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)
3.15 Environment and safety

3.15.1 Policy needs
During the sixties and seventies, transport models were used and developed mainly for evaluating infrastructure decisions. However, nowadays other aspects become more and more important. Especially local air quality, general environmental issues and safety issues have increasingly become major evaluation criteria due to increased political attention to these issues and all kinds of regulation, which are largely based on European guidelines. EC Regulations provide that new infrastructure plans must be assessed for their impact on things like air quality and noise pollution.

European guidelines prescribe that all infrastructure projects must be assessed on their environmental impact by means of an environmental impact assessment (EIA). EIAs are associated with project decisions, usually the final decisions before construction starts. These are detailed decisions which are usually concerned with the location and design of a project and the adoption of measures to mitigate, rather than prevent, the environmental impact. Feasible alternatives at the project stage are often limited to minor alternative scenarios.

However, strategic transport policy plans which could have an impact on an infrastructure investment plan also need to be assessed for their environmental impact. This is called a Strategic Environmental Assessment (SEA) of Transport Infrastructure Plans (more information can be found on http://ec.europa.eu/environment/eia/sea-support.htm). SEAs are associated with decisions on, for example, demand management options, modal solutions or different routes. An SEA may therefore influence decisions on the need for and the mode and location of transport infrastructure projects and, hence, on the scope of the project EIA. An important feature of an SEA is that it enables an assessment of the impact on the transport flows in a region or indeed a country and their associated effects. As such, an SEA relies on using appropriate forecasting methods. To clarify this, the construction of a new high-speed (HSR) rail link and the construction of new road infrastructure may serve as an example. A new HSR link may attract traffic from parallel highways or contribute to mitigating airport congestion. Conversely, the increase in capacity generated by new road infrastructure may lead to bottlenecks that have not been foreseen at the project level. Figure 3-9 shows the main differences between an SEA and project EIA.
Environmental impact models are models which calculate the external effects which indirectly arise from transport demand. Newberry (1990) identified the following effects that should be taken into consideration:

- Road damage costs (including maintenance cost and road wear);
- Traffic noise;
- Local emissions (air quality);
- Global emissions (including climate effects);
- Accidents; and
- Barrier effects.

The implementation of impact models requires models that link transport demand to environmental impacts. The need for information differs for each application. However as a rule, the output of a transport model will need some adjustment to be used as input for an environmental impact study. The following adjustments are commonly made:

- In environmental studies (e.g. air quality studies), the output for an average workday needs to be converted to an average weekday.
• CO₂ assessments require information about the composition of the car fleet;
• Traffic safety impact assessments require information about the demographic structure of the transport users (younger people have significantly different risk factors compared to older people); and
• Noise impact studies require information about the share of traffic that produces noise in the evening and during the night.

Table 3-45: Transport models for environmental and safety impact assessments according to regional detail and passenger/freight

<table>
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<th>Regional detail</th>
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<th>Urban / regional</th>
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<th>national models incl. international</th>
<th>international models</th>
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</thead>
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<td>Passenger / freight</td>
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<td></td>
<td></td>
<td></td>
</tr>
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<tr>
<td></td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

3.15.2 Organisation

The following organisational issues are important when developing a tool to conduct an environmental impact assessment:

• **Budget, Planning, Ambitions.** An environmental impact assessment is not something that can be done in a few days after running the transport model. It is an independent activity and needs a budget and attention accordingly. The amount of the budget will depend on the scope of the project impact assessment. If all kinds of impacts are to be taken into account, the budget may well exceed the costs of the transport demand forecast.

• **Project organisation.** In most cases, an environmental impact assessment is done after the calculations have been made using the transport model. That is only logical, except that there is one complication. During the project assessment it often happens that new insights occur which lead to changes in a particular project alternative. This will also automatically lead to new forecasts having to be made using the transport model. The project organisation should be aware of this iterative process. To assume that it is a sequential process is true when one looks at the calculations, but the decision-making process is much more iterative. This is even more true when dealing with an SEA.

• **Scope and type of model.** These are determined by the type of environmental assessment conducted. If it is conducted at project level, a detailed transport model will be needed. However, when the environmental impact assessment is done at the strategic level, a multi-modal transport model should be used which is capable of including all kinds of feedback.
• **Choice of software/GIS.** Most environmental assessment techniques need specific models. Examples include dispersion models to assess air quality. Special attention should be paid to linking the environmental model to the transport model.

• **Establish maintenance procedure.** In this case, a great deal of attention should be given to transparency. This requires proper documentation of the underlying assumptions and of the way in which transportation model is linked to the environmental model.

• **Tendering, who will build the model.** Environmental impact assessments are usually conducted by specialised consultants. Large engineering companies will be able to do both. There are benefits and downsides to both approaches. Either way, it should be clear and transparent how a proper interfacing between the transport model output and project impact assessment input is guaranteed.

<table>
<thead>
<tr>
<th>Table 3-46: Transport models for environmental impact and safety assessments according to modes of transport and passenger/freight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>modes</strong></td>
</tr>
<tr>
<td>road</td>
</tr>
<tr>
<td>rail</td>
</tr>
<tr>
<td>iww</td>
</tr>
<tr>
<td>sea/ferry</td>
</tr>
<tr>
<td>air</td>
</tr>
<tr>
<td>road/rail</td>
</tr>
<tr>
<td>road/air</td>
</tr>
<tr>
<td>road/rail/iww</td>
</tr>
<tr>
<td>road/rail/sea</td>
</tr>
<tr>
<td>road/rail/air</td>
</tr>
<tr>
<td>road/rail/slow</td>
</tr>
<tr>
<td>road/rail/iww/sea</td>
</tr>
<tr>
<td>road/rail/iww/slow</td>
</tr>
<tr>
<td>road/rail/sea/air</td>
</tr>
<tr>
<td>road/rail/ferry/air/slow</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

3.15.3 Model development
The environmental impact assessment will play an important role in policy decisions. A good quality environmental impact assessment can help decision-makers form an opinion. This will, however, require maximum transparency. Policymakers are not particularly fond of a black box approach. It is, therefore, necessary to know the conditions and assumptions underlying the assessment.

Last but not least it should be realised that the outcomes of the environmental impact assessment involve all sorts of uncertainties (see section 10.1.2.3 of part 3). The outcomes are based on multiplying transport data by all kinds of other variables. It is therefore
recommended the uncertainty of the outcomes is understood, for example, by conducting a sensitivity analysis (e.g. 10% less transport growth, different emission factors).

Table 3-47: List of models from MDir that can be used for environmental impact and safety assessments

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATTACK</td>
<td>N  \  R</td>
<td>Netherlands</td>
<td>DRAG-Stockholm</td>
<td>NK</td>
<td>Sweden</td>
</tr>
<tr>
<td>POINT</td>
<td>N  \  R</td>
<td>Netherlands</td>
<td>TRULS</td>
<td>N  \  R</td>
<td>Norway</td>
</tr>
<tr>
<td>PRIMES</td>
<td>NK</td>
<td>EC</td>
<td>NMT-4</td>
<td>N  \  R</td>
<td>Norway</td>
</tr>
<tr>
<td>TREMOVE</td>
<td>NK</td>
<td>EC</td>
<td>SIMTRAP</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>Forecasting Air pollution by Car Traffic Simulation (FACTS)</td>
<td>U \  R</td>
<td>Netherlands</td>
<td>Econometric Model for Calculating the Energy Consumption and Emissions from the Transport Sectors in the National Macroeconomic model ADAM</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>MITHRA</td>
<td>U \  R</td>
<td>France</td>
<td>BVWP Freight Transport Model</td>
<td>N \ I</td>
<td>Germany</td>
</tr>
<tr>
<td>SUBMESO</td>
<td>U \  R</td>
<td>France</td>
<td>PRIMOLA</td>
<td>N \ I</td>
<td>Italy</td>
</tr>
<tr>
<td>ORPHEA</td>
<td>U \  R</td>
<td>France</td>
<td>System dynamics for transport ( MODUM )</td>
<td>NK</td>
<td>not known</td>
</tr>
<tr>
<td>Modele Strategique de Deplacements de l'agglomeration Lyonnaise</td>
<td>U \  R</td>
<td>France</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)

3.16 Capacity utilisation

3.16.1 Policy needs

Europe is endowed with a dense transport network and generally high-quality infrastructure. However, many areas and cities in Europe suffer from congestion. Goods transport in the EU grew by 28% and passenger transport by 18% during the period 1995-2004, with road transport growing by 35% and 17%, respectively. Short-distance sea shipping grew at almost the same rate. Rail freight transport in those Member States that have opened up the rail market early showed a greater increase compared to the other Member States. Overall, rail freight transport rose by 6% in 1995-2004. Rail passenger transport has increased considerably, mainly driven by high-speed rail links. Intra-EU air travel grew by more than 50% in the same period despite the September 11 attacks. The European Commission expects that by 2020 60 major airports will have become severely congested and a similar trend is envisaged for ports. Inland waterways transport have experienced strong growth in several Member States in the last decade.

A range of policy instruments are available to alleviate congestion and improve mobility, e.g. improved infrastructure, intelligent mobility solutions, demand management, and user charges. In a 2006 mid-term review of the White Paper, the European Commission emphasised that optimisation was required both with regard to the potential of existing modes of transport and with regard to their combined use.
The table below shows that 14 models are specifically suitable for capacity utilisation.

### Table 3-48: Transport models for capacity utilisation according to regional detail and passenger/freight

<table>
<thead>
<tr>
<th>Passenger / freight</th>
<th>Regional detail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
<td>urban/regional</td>
</tr>
<tr>
<td>full</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>passenger</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>freight</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>both</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>

#### 3.16.2 Organisation

The following organisational issues are important when developing a transport model for capacity utilisation:

- **Budget, Planning, Ambitions.** Capacity utilisation models include a wide spectrum of models in terms of modes of transport and level of detail required for the study. Therefore, budget, planning and ambitions very much depend on the study objectives.
- **Project organisation.** It is usually good practice to include stakeholders with knowledge of specific capacity issues.
- **Scope and type of model.** These may vary according to the objectives and range from simple route-choice models to complex multi-modal models with capacity restrictions.
- **Choice of software/GIS.** This is no different than for other models. GIS can be useful to present the results to stakeholders.
- **Establish maintenance procedure.** A regular updating and improvement procedure should be put in place similar to that for other models, except in the rare case of a simple model.
- **Tendering.** The development of this type of model may require a tendering procedure.

The table below shows the capacity utilisation models by mode and scope.

### Table 3-49: Transport models for capacity utilisation according to modes of transport and passenger/freight

<table>
<thead>
<tr>
<th>modes</th>
<th>passenger/freight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not known</td>
<td>passenger</td>
</tr>
<tr>
<td>road</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>rail</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>road/rail</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>rail/air</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>road/rail/ww/sea</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0</strong></td>
<td><strong>8</strong></td>
</tr>
</tbody>
</table>
3.16.3 Model development

Studies on the optimisation and utilisation of infrastructure need to consider the relationship between volumes and capacity limits. Accordingly, capacity utilisation modelling primarily involves assignment procedures.

Traditionally, route-choice models for road transport consider capacity restriction by using speed-flow curves at the link level. In particular, these models should also consider intersection delays in urban areas, given that these are major contributors to overall journey times. Depending on the severity of road congestion and required accuracy, traditional route-choice models may be insufficient and other methods called for, e.g. models using simulations of individual vehicles. Several commercial software programmes are available with good quality interfaces; however, they often need to be used with care to reflect actual travel behaviour.

Capacity issues in public transport are more complex than for car traffic. Consequently, traffic models seldom include the direct impact of packed buses and trains. If all seats are taken, people have to stand or may even miss their train or bus, which is inconvenient and may lead to longer waiting times. Bus services are also influenced by road traffic conditions, because any increase in road traffic congestion will delay buses and result in longer journey times. A common approach is to assume unlimited capacity in public transport, run the assignment and compare the outcome with the existing capacity afterwards. If existing capacity is exceeded, the provision of public transport may be increased or journey times manually corrected.

In freight transport, capacity concerns the movement of goods over the infrastructure (road, rail, and waterways) and terminal handling. Thus, the aspect of capacity becomes quite complex in terms of multi-modal transport. The state-of-practice in modelling is to consider capacity restriction as a separate element of the transport chain. Road congestion is considered in the route-choice model at the same time as passenger cars are assigned. In the network model, transfer times at terminals could be included approximately, while detailed terminal handling and logistics are usually covered by other models. In the TRANS-TOOLS model, however, logistics are modelled in a separate model linked to mode choice and route choice models.
Table 3-50: List of models from MDIR that can be used for capacity utilisation modelling

<table>
<thead>
<tr>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
<th>Model name</th>
<th>Regional detail</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>European Union Network Model</td>
<td>I</td>
<td>EC</td>
<td>Congestion costs model (FileKosten Model-FMK)</td>
<td>U\R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>East-West Route Traffic Model</td>
<td>U\R</td>
<td>UK</td>
<td>Freeway Operations (FOSIM)</td>
<td>U\R</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Road Transport Model of Hungary</td>
<td>N\R</td>
<td>Hungary</td>
<td>Congestion explorer (Congestieverkenner)</td>
<td>U\R</td>
<td>Switzerland</td>
</tr>
<tr>
<td>Hungary Corridor Model</td>
<td>N\R</td>
<td>Hungary</td>
<td>CAPRES</td>
<td>I</td>
<td>Germany</td>
</tr>
<tr>
<td>'Saturn'</td>
<td>U\R</td>
<td>Portugal</td>
<td>Schenarios.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SETA 'EMME/2' model</td>
<td>U\R</td>
<td>Portugal</td>
<td>Hungarian models developed by TRANSMAN</td>
<td>U\R</td>
<td>Hungary</td>
</tr>
<tr>
<td>SMILE</td>
<td>N\R</td>
<td>Netherlands</td>
<td>Engineering</td>
<td>U\R</td>
<td>Hungary</td>
</tr>
<tr>
<td>ESIM</td>
<td>U\R</td>
<td>Netherlands</td>
<td>PROCZ</td>
<td>N\I</td>
<td>Poland</td>
</tr>
</tbody>
</table>

(NK not known, I = international, N = national, R = regional, U = urban)
4 Conclusion

In this handbook on transport modelling, we have chosen two approaches to guide the reader to the best possible and most practical models available. In the first section of the handbook we have described the process of model construction, giving a concise overview of all the steps that need to be taken to develop a transport model. In the second part of the handbook we have looked at the modelling process in terms of different policy indicators in order to provide a better understanding of the specific modelling issues that are related to the policy indicators. In this part, we have also provided an overview of existing models that are related to the policy indicators. We have included in the project a modelling directory (MDir, which is a database containing 306 European transport models and which is updated from a previous European project). The list of models reflects past experience with modelling on the various issues covered. It also shows the scope and scale of the models that have been developed.

In addition, this handbook is supported by two annexes which also reflect this two-pronged approach, the first annex describing state-of-the-art modelling techniques, with the second giving a detailed description of best practices in transport modelling. Cross references are given to guide the reader to these detailed descriptions of state-of-the-art modelling techniques and best practices in transport modelling.

We hope this two-way approach will provide the reader with a better understanding of the different aspects involved in constructing a transport model, and will contribute to improved and more transparent modelling practices in Europe. Improved and more efficient transport modelling will save costs at the modelling stage. At the same time, high-quality transport modelling will lead to better decision-making by policy-makers which, in turn, will contribute to improved decision-making at the Europe level. This especially holds true for countries where certain transport models are still under construction or perhaps non-existent.
Appendix A: Modelling Directory

The MDir (Modelling Directory) database defines 57 features by which models are described. The relevance of the models in terms of policy-making plays an important role for all features, i.e. what type of transport does the model cover (passenger/freight), on what scale does the model operate? As such, the MDir will help policy-makers/modellers to learn from past experience. MDir was first developed under the 4th Framework Programme and has been extended under the MOTOS project. The MDir is regularly updated and covers 306 European transport models. This will hopefully lead to improved decision-making by policy-makers and will allow modellers to see whether similar models have already been used in other countries. Details of the models are given in an ACCESS database that is available on the MOTOS website.

<table>
<thead>
<tr>
<th>Features of the model</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of model</td>
<td>The official title of the model (acronym, if any)</td>
</tr>
<tr>
<td>Abstract</td>
<td>A very concise summary of the main purpose of the model, its scope of application, basic construction principles and added value</td>
</tr>
<tr>
<td>Policy relevance</td>
<td>The policies for which the model can be useful</td>
</tr>
<tr>
<td>Geographical scale</td>
<td>The actual geographical coverage of the model (for instance, European, international, regional, national, local)</td>
</tr>
<tr>
<td>Time horizon</td>
<td>For the forecasting model:</td>
</tr>
<tr>
<td></td>
<td>- the latest base year, if any</td>
</tr>
<tr>
<td></td>
<td>- the forecast year(s), if any</td>
</tr>
<tr>
<td></td>
<td>- or the time span possible to forecast</td>
</tr>
<tr>
<td>Scope of the model</td>
<td>Strategic, tactical, operational, DSS</td>
</tr>
<tr>
<td>Transport domain</td>
<td>The type(s) of transport covered by the model</td>
</tr>
<tr>
<td>Intermodality</td>
<td>The transport modes covered</td>
</tr>
<tr>
<td>Type of transport modelling formulation</td>
<td>The key underlying assumptions or approaches, the basic parts of the model</td>
</tr>
<tr>
<td>Integration with other forecast models</td>
<td>The other forecast models in combination with which it is used, if any</td>
</tr>
<tr>
<td>Integration with evaluation tools</td>
<td>The evaluation tools for which the (sub)results of the model are used</td>
</tr>
<tr>
<td>Integration with decision tools</td>
<td>The decision tools for which the (sub)results of the model are used</td>
</tr>
<tr>
<td>Modeller</td>
<td>The name of the company(ies) or person(s) who developed the model</td>
</tr>
<tr>
<td>Proprietor</td>
<td>The owner of the model</td>
</tr>
<tr>
<td>Status</td>
<td>e.g. public, non-public</td>
</tr>
<tr>
<td>Applications</td>
<td>The cases and/or areas to which the the model has been or can be applied</td>
</tr>
<tr>
<td>Legal aspects</td>
<td>Key legal aspects, identifying for instance the organisations authorised to use the model, etc.</td>
</tr>
<tr>
<td>Features of the model</td>
<td>Interpretation</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Commercial aspects</td>
<td>Key commercial aspects, e.g. can the model be purchased or accessed, etc.</td>
</tr>
<tr>
<td>Input database structure</td>
<td>Input datasets or variables</td>
</tr>
<tr>
<td>Network definition</td>
<td>If relevant, the network type, number of links and nodes, level of detail, networking criteria</td>
</tr>
<tr>
<td>Zoning</td>
<td>If relevant, the territorial units used as zones, (approximate) total number of zones, specific zoning criteria</td>
</tr>
<tr>
<td>Organisational network</td>
<td>If relevant, the criteria used for to define public transport (passenger) or intermodal networks (freight)</td>
</tr>
<tr>
<td>Surveys</td>
<td>The survey information used as input or to validate the model (if any)</td>
</tr>
<tr>
<td>Traffic counts</td>
<td>The count data used in the model (if any)</td>
</tr>
<tr>
<td>Socio-economic data</td>
<td>The socio-economic data used in the model (if any)</td>
</tr>
<tr>
<td>Base matrix</td>
<td>Features of the base matrix(ies) of the model</td>
</tr>
<tr>
<td>Generalised cost functions</td>
<td>The variables that make up the cost function, and any other relevant aspects</td>
</tr>
<tr>
<td>Type of user and unit</td>
<td>The units and dimensions used in the model</td>
</tr>
<tr>
<td>Trip purposes</td>
<td>If relevant to passenger models, how many and what trip purposes are considered in the model</td>
</tr>
<tr>
<td>Time values for user and trips</td>
<td>The time values considered in the model (for instance annual, monthly, weekly, daily, peak hours, etc.)</td>
</tr>
<tr>
<td>Network calibration process</td>
<td>If relevant, the data and techniques used as conditions for calibration of the network(s)</td>
</tr>
<tr>
<td>Trip generation</td>
<td>The assumptions and parameters underlying trip generation modelling and analysis</td>
</tr>
<tr>
<td>Trip distribution</td>
<td>The methods and approaches used in modelling trip distribution (e.g. the gravity distribution model, entropy-maximisation approach, etc.)</td>
</tr>
<tr>
<td>Modal split</td>
<td>If relevant, the techniques used to model the modal split</td>
</tr>
<tr>
<td>Other O-D matrix projection issues</td>
<td>Any other aspects relevant to projecting the O-D matrices</td>
</tr>
<tr>
<td>Scenarios: exogenous hypothesis</td>
<td>The exogenous scenario(s) and/or hypothesis applied to the model, if any</td>
</tr>
<tr>
<td>Periodicity</td>
<td>The periodicity factor used in the model</td>
</tr>
<tr>
<td>Assignment</td>
<td>The assignment methods and techniques used in the model (all-or-nothing, stochastic methods, congested assignment, etc.)</td>
</tr>
<tr>
<td>Sensitivity test</td>
<td>The type(s) of sensitivity test which have been or can be performed in the model</td>
</tr>
<tr>
<td>Type of result</td>
<td>The type of result produced by the model</td>
</tr>
<tr>
<td>Output database structure</td>
<td>Main features of the output database</td>
</tr>
<tr>
<td>Audits</td>
<td>The type(s) of audit performed (if any)</td>
</tr>
<tr>
<td>Literature</td>
<td>Literature on which the model is based</td>
</tr>
<tr>
<td>Modelling software</td>
<td>i.e. EMME/2, POLYDROM, (Micro)TRIPS, MINUTP, PTVision, SATURN, QVIEW, Pascal/Delphi, etc.</td>
</tr>
<tr>
<td>Features of the model</td>
<td>Interpretation</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Statistical software</td>
<td><em>i.e. SPSS, ALOGIT, EXCEL, etc.</em></td>
</tr>
<tr>
<td>Database software</td>
<td><em>i.e. Access, FoxPro, Visual Basic, etc.</em></td>
</tr>
<tr>
<td>GIS software</td>
<td><em>i.e. Arcview, ArcInfo, MapInfo, etc.</em></td>
</tr>
<tr>
<td>Hardware and OS</td>
<td><em>Minimum requirements for the hardware and operational system</em></td>
</tr>
<tr>
<td>Expected running time</td>
<td><em>Approximate time necessary to run the entire model</em></td>
</tr>
<tr>
<td>Usability</td>
<td><em>Availability of a model description, and in what language(s), the kind of expertise necessary to run the model and understand the output results</em></td>
</tr>
<tr>
<td>Planned improvements</td>
<td><em>Planned future improvements, if any</em></td>
</tr>
<tr>
<td>Validated by proprietor</td>
<td><em>Full or partial validation (if any) of the model in terms of the results produced</em></td>
</tr>
<tr>
<td>Validated by scientific committee</td>
<td><em>Validation (if any) of the quality of the scientific component parts of the model by a scientific committee</em></td>
</tr>
<tr>
<td>Who filled completed the form</td>
<td><em>Name of the person who filled in the form</em></td>
</tr>
<tr>
<td>Evaluation</td>
<td><em>The strengths and weaknesses of the model</em></td>
</tr>
</tbody>
</table>
PART 3: State-of-the-art report
SIXTH FRAMEWORK PROGRAMME
FP6-2004-SSP-4

Scientific Support to Policies (SSP)
“Integrating and Strengthening the European Research Area”

Acronym: MOTOS
Full title: Transport Modelling: Towards Operational Standards in Europe
Proposal/Contract no.: TREN/06/FP6SSP/S07.56151/022670
Start date: 1st June 2006
Duration: 12 months

<table>
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</thead>
<tbody>
<tr>
<td><strong>Document number:</strong> MOTOS/D2.1/PU/v4.0</td>
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<tr>
<td><strong>Date of delivery:</strong> 30th of March 2007</td>
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<td><strong>Work package:</strong> WP2</td>
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<td><strong>Lead participant:</strong> CTT, DTU</td>
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**Abstract:**
This report is delivery 2.1 in work package 2 of MOTOS. It describes economic, freight, demand, assignment, and impact modelling in state-of-the-art transport models.

**Keywords:**
MOTOS WP2, state of the art, best practice, transport modelling
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1 Introduction

This report provides an overview of state of the art and best practice in transport modelling in Europe. It is the main delivery of work package 2 (WP2) of the MOTOS project.

1.1 The MOTOS project

The MOTOS project aims at the integration of transport modelling in the enlarged union. The high-level goal of MOTOS is:

To support transport policy in Europe, by defining common good practice principles for national and regional transport modelling that satisfy immediate needs of model developers in the New Member States and contribute to the establishment of a standardised approach for transport modelling in the European Union.

The project emphasises the importance of user needs and best practice as influential factors in the process of improving the general standards in modelling.

1.2 WP2 of MOTOS

The purpose of WP2 is to produce reports on state of the art and best practice within transport modelling that can form the basis for a handbook on best practice in transport modelling. The output should describe characteristics of best practices for different types of transport modelling in the main areas freight demand, passenger demand, economic, and assignment modelling. Furthermore, the output should focus on how different models are linked, e.g., how regional models link to a national model.

The WP2 of MOTOS has two deliverables:

- D2.1 Report on state of the art, best practice examples, and linking of models
- D2.2 Report on common best practice principles

Comments from the concluding meeting of WP1 and deliverables from WP1, e.g., the user needs collected in the New Member States, have formed the basis of the discussion on user needs in the present report. The two reports, D2.1 and D2.2, have been structured so that the first gives an overview of state-of-the-art modelling and linking of models, together with a summary of best practice examples. The second report describes common best practice principles and gives detailed descriptions of the examples. Hence, the second report can be seen as an appendix of the first.

1.3 Contents and main findings

Chapter 2 gives a short summary of the policy issues and user needs that the models should support based on WP1 and, how they differ between EU, EU15, and New Member States (NMS). This is seen from the fact that EU emphasises EU-level and strategic models, EU15 emphasise national and tactical models, whereas the NMS prioritise regional and operational
models. The difference between EU and the sub groups is natural while the difference between EU15 and NMS should disappear if integration and cooperation between modellers and decision-makers are done properly. While the difference in interests is a challenge, this report seeks to show that proper tools exist to address all the needs.

The second part of the report (Chapters 3 to 5) introduces the reader to different aspects of transport modelling and data issues.

Chapter 3 is the first of two chapters on general aspects of transport modelling. The chapter emphasises the role of the planning context and defines two main dimensions of a model: geographical scale and time horizon. Chapter 4 discusses the basic tools of transport modelling. It introduces the important concepts: demand, supply, and equilibrium. Furthermore, it introduces estimation, calibration, and validation procedures, and emphasises the need for proper validation in transport modelling. Finally, the chapter discusses some issues, e.g., pivot-point methods, related to the application of a model. Chapter 5 discusses the central relationship between model and data. On one hand, data needs depend on course on the nature of the model. On the other hand, design of the model must reflect available data sources. Therefore, the base of a model is the quality and amount of available data, and strictly speaking, no model is better than the data it is founded on. A second important concern in data collection is the cost. Since costs for new data collections often are quite high, it is important before designing the model to review existing data sources. Therefore, an inventory of existing data should always be conducted in the initial phase of the model development as a base for model design and to estimate the need for new data collections.

The third part of the report gives a state-of-the-art overview of the specific areas freight, passenger demand, economic and assignment modelling, socio-economic assessment methods and impact modelling in Chapters 6 to 11 respectively.

Chapter 6 focuses on freight modelling, and the increasing importance that elements like logistics are integrated into a freight model. A main concern is a lack and inconsistency in data to support freight modelling. Chapter 7 gives an overview of passenger demand modelling. The discussion ranges from the classic four-step models to advanced activity-based models. The use of disaggregated data to estimate tour-based nested logit models provides today the best practice in passenger demand modelling. Moreover, the mutual dependencies between the transport systems and the wider spatial environment (including economy, technology, social systems, land-use, ecological systems, etc.) are discussed. Chapter 8 discusses the linkage between economic activity and the derived transport demand. Methodologically, the chapter gives an overview of economic models ranging from simple input-output models to advanced computational general equilibrium (CGE) models with endogenous price formation. Chapter 9 presents different frameworks often used for traffic assignment modelling. The chapter exemplifies methods used in route choice for cars, public transport and rail. The state of practice in assignment modelling considers multiple user classes, overlaps of routes and heterogeneity of travellers’ preferences.

Chapter 10 describes economic assessment procedures and includes a discussion of Cost Benefit Analysis (CBA) and Multi-criteria Analysis (MCA). Whereas the CBA includes direct measurable costs and benefits related to a project, MCA makes it possible to include
wider economic measures, which are not directly accounted for in the CBA. Chapter 11 discusses ways to model external effects resulting from transport. Included is a discussion concerning models for traffic accidents, traffic noise, road wear, emissions, and barrier effects. In addition, valuation principles are considered as are the use of Geographical Information Systems as a tool to explore spatial effects.

The last part of the report consists of Chapter 12 on linking of scales and Chapter 13 containing a summary of best practice examples.

Chapter 12 focuses on the way different sub-models and model levels can work together through linking. The two main examples are the national model of Sweden and the EU-level model TRANS-TOOLS. Chapter 13 provides a brief overview of different best practice examples. They have been chosen to cover most of Europe and the different subjects: freight, passenger, economic, and assignment modelling.

The two last chapters are a vocabulary list in Chapter 14 and a literature list in Chapter 15.
2 User needs

The user needs have been identified in an earlier phase of this study ‘User needs and current state of affairs’ within the workshops that were held in Poland, Czech Republic, Hungary, and Lithuania. This section summarises the main points from that investigation. The user needs are divided into the following two categories

1) User needs within EU15
2) User needs in New Member States

Further, the user needs within EU15 can be divided into EU-level White Paper issues, and issues that may emerge from the specific member states and regions. These categories are explained in more detail below.

2.1 User needs identified in the EU white paper

The first category consists of the issues addressed in TNO (2006b). This report centres on The White Paper “European Transport Policy for 2010: Time to Decide”. The paper is the reference of the European Union’s Common Transport Policy. It proposes the following main policy objectives:

- rebalancing transport modes and promoting intermodality; In the mid-term review of the White Paper, this issue has been reformulated into “co-modality” wherein it is stressed that within the transport system different modes of transport should be more cooperating instead of aiming at strict competition;
- improving efficiency of infrastructures targeting bottlenecks;
- attaining safe and user-friendly transport, and
- managing globalisation of transport (including both the EU enlargement process and representation at international level).

Transport policy should not be seen in isolation – transport is not a mean in itself - but in relation to other areas: primarily, energy and environmental policies are relevant, but other tight links exist with:

- economic policy and impacts on transport of production models and stock rotation;
- land-use planning policy and increasing sprawl;
- social and education policy in terms of flexible working and school hours;
- urban transport policy in major conurbations/ metropolitan areas;
- budget and fiscal policy to achieve internalisation of transport external costs;
- competition policy to ensure the opening up of markets, especially the rail sector;
- transport research policy to make the various efforts at Community, national, and private level more consistent along the lines of the European Research Area, and
- security and safety.

2.1.1 Summary of White Paper in 12 policy areas

The user needs of the White Paper can be divided into 12 policy areas. The core of The White Paper consists of four chapters that each introduces one action priority of the Commission.
The 12 White Paper policies have been grouped in these four action priorities according with the target they hit.

**Action priority 1: Shifting the balance between modes of transport**

1. **Improving quality in the road transport sector**
   Protecting carriers from consigners and bringing about modernisation of the way in which road transport services are operated, while complying with the social legislation and the rules on workers’ rights.

2. **Revitalising the railways**
   Opening up the markets, not only for international services, but also for cabotage on the national markets and for international passenger services. Secondly, restoring the credibility, in terms of regularity and punctuality of this mode, particularly for freight.

3. **Striking a balance between growth in air transport and the environment**
   Reorganisation of Europe’s sky and ensuring the expansion of airport capacity remains subject to demands of reduction of noise and pollution caused by aircrafts.

4. **Promoting transport by sea and inland waterway**
   Reinforcing the position of these two modes by improving infrastructure and harmonising social rules and technical requirements.

5. **Turning intermodality into reality**
   Technical harmonisation and interoperability between systems, particularly for containers and support for innovative initiatives.

**Action priority 2: Eliminating bottlenecks**

6. **Building the Trans-European transport network**
   The main aims are: Removing the bottlenecks in the railway network; completing the routes identified as the priorities for absorbing the traffic flows generated by enlargement, particularly in frontier regions; and improving access to outlying areas.

Priority is given to freight and a high-speed network for passengers. The main obstacle to carrying out infrastructure projects, apart from technical or environmental considerations, remains the difficulty of mobilising capital. The White Paper argues that innovative methods of public-private funding must be applied.

**Action priority 3: Placing users at the heart of transport policy**

7. **Improving road safety**
   Of all modes of transport, transport by road is the most dangerous and the most costly in term of human lives. The White Paper argues that users expect stricter road safety measures, such as improved road quality, better training of drivers, enforcement of traffic regulations, checks on vehicle safety and road campaigns. Furthermore, The White Paper argues for further harmonisation of signs at dangerous black spots and harmonisation of the rules governing...
check and penalties for international commercial transport with regard to speeding and drunk driving.

8. **Adopting a policy on effective charging for transport**

    Containing congestion in Europe, tackling the greenhouse effect and building infrastructure while at the same time improving safety on the road or in public transport and minimising environmental disturbances, all comes at a price. And on top of this social cost comes the cost of investment. Transport users are entitled to know what they are paying for and why. Therefore, Community action aims at gradually replacing existing transport system taxes with more effective instruments for integrating infrastructure costs and external costs. The White Paper aims to harmonise fuel taxation for commercial users, particularly in road transport and charging for infrastructure with integration of external costs.

9. **Recognising the rights and obligations of users**

    Transport is a service of general interest for the public benefit. This is why the Commission wants to encourage measures in favour of intermodality for people and pursue its action on users’ rights in all modes of transport, while also considering whether in the future it might also introduce user obligations. The White Paper aims to lay the foundation for helping the transport users to understand and exercise their rights and also for defining certain safety-related obligations.

10. **Developing high quality urban transport**

    Noise and air pollution and their effects on health are of greater concern in towns and cities, and a clear line needs to be drawn urgently between the respective roles of private cars and public transport. Given the constraints of the principle of subsidiary, the Commission intends essentially to encourage the exchange of good practice and taking regulatory initiatives to encourage the use of diversified energy in transport.

11. **Putting research and technology at the service of clean, efficient transport**

    Adoption of stricter standards for noise, safety, and emissions. Secondly, integrating intelligent systems in all modes to make for efficient infrastructure management.

**Action priority 4: Managing the globalisation of transport**

12. **Managing the effects of globalisation**

    Reinforcing the position of the Community in international organisations in order to safeguard Europe’s interests at world level. The White Paper puts emphasis on achieving independence in the field of satellite radio navigation.

Investigations related to the mid-term assessment of the White Paper revealed that countries have adopted the principles of the White Paper in their national transport policy making. Table 2.1 below shows that the implementation differs within the EU. It should be mentioned that transport modelling tools and data provide an essential part of evaluating transport

---

1. ASSESS (see TML, 2005) Assessment of the contribution of the TEN and other transport policy measures to the mid-term implementation of the White Paper on the European Transport Policy for 2010, INTERIM REPORT, May 2005
policies. It is seen from the table that the NMS are lacking behind with the implementation of the transport policies.

<table>
<thead>
<tr>
<th>DGTREN policies</th>
<th>EU 15</th>
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<td>Balancing air transport and environment</td>
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<td>Effective charging for transport</td>
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<td>Enabling clean, efficient transport</td>
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<tr>
<td>Managing the effects of globalization</td>
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Table 2.1: Implementation of White Paper policies in 2005

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<tr>
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<td>Light blue</td>
<td>Low implementation</td>
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2.2 User needs within the EU15 member states

In addition to the supranational policy actions and legislation provided by the EU, Member States have individual transport policies and legislation. The following policy issues of individual member states within EU15 are relevant for the MOTOS project.

- Economic sustainability
- External effects and their pricing
- Modal split
- Local traffic and congestion
- Feedback processes economy-infrastructure investment
- Accessibility and reliability of transport networks
- Correlation of transport with economic activity-decoupling
- Transport as a driver of the economy
- Transport efficiency
- Effect of international transport flows
- Safety and security
- Analysis of specific areas
- Sectorial analysis
- Compliance to Commission policies
- Growth of freight transport
- Logistic performance
Economic sustainability
Transport, especially aviation and shipping, provides a vital connection to other continents for both passengers and freight, as well as land-based transport within mainland Europe. Almost all member states want to support the national economy in the European (and global) welfare by facilitating the free movement of people and goods in and out of the country by land, air, or sea, while minimising the negative effects on the communities around the infrastructure and on the ecological environment. Some countries, like Germany, Belgium and France, have included the strengthening of the entrepreneurial climate in their transport policy.

External effects and their pricing
Internalisation of external effects of transport is becoming standard in the analysis of transport in member countries. External effects include congestion, emissions, accidents, land use, and so on. In various countries, pricing of external effects becomes an active instrument in transport policies. ‘Fair infrastructure charging’ can notably be seen in Austria, Germany with the MAUT, UK (London), Netherlands, Belgium, and Switzerland. EU and member states have different attitudes and strategies towards pricing.

Modal split
Modal split is one of the issues that are already included in the national policies by many member states (e.g., Finland, Denmark, Germany, the Netherlands, Belgium, UK, Italy, and Portugal). Germany and UK already promote multimodal transport through a fixed freight grant regime. Countries along the North Sea, Baltic Sea, and Mediterranean Sea are focussing on the promotion of their ports in general and of short sea shipping in particular. Inland shipping is mainly promoted by Belgium, the Netherlands and Germany. In addition, some countries along the Danube, Seine, and Rhone are looking for strategies to promote inland waterways transport. The Alpine countries have traditionally investment in rail transport to a large extent in their plans. These countries consequently promote this transport mode.

Local traffic and congestion
Congestion is an issue in highly populated areas. A coupling of local traffic with congestion is needed to address the effect on long-distance traffic. Therefore, congestion plays an important role in traffic and transport policies in UK, Netherlands, Germany, Belgium, France and Italy (e.g., see the modelling overview of SPOTLIGHTS project). One of the issues in congestion is the interaction between freight and passenger flows, since it is expected that freight transport volumes will grow considerably.

Feedback processes economy-infrastructure investment
Indirect effects of infrastructural investment are studied in the Netherlands (e.g., OEI methodology) and UK (e.g., SACTRA). The HEATCO project concludes that a few other countries include indirect economic effects in their investment studies. And if included, it is mostly done on ad hoc basis and not via a pre-determined format. Especially in New Member States and Accession Countries infrastructure investment has a substantial influence, since investment has a large effect on marginal productivity, as a consequence of improved accessibility. In addition concerns about international competitiveness of the EU economy are important here: the two-way relation between worldwide networks and global trade. “Freight and the economy” discussion: what are costs and (mainly indirect) benefits of freight investments?
Accessibility and reliability of transport networks
The Netherlands, Flemish, French, German and UK transport policies emphasise the role of accessibility and reliability of the main and transport networks. Reliability will be improved so that travellers know at what time they will arrive and transporters can deliver just-in-time. This improvement is to take place at every stage of the journey: ‘from door to door’ in other words. National, regional, and local networks of road, water, and public transport are closely related. For this reason, an integrated network approach is necessary. In addition the creation of seamless multimodal networks, new focus on Motorways of the Sea, and inland waterways can be mentioned here.

Correlation of transport with economic activity-Decoupling
Decoupling is an issue in the sense that economic growth is always accompanied with transport growth. Especially, the Netherlands, Germany, and the UK are including decoupling in their transport policy.

Transport as a driver of the economy
The economic activity of the transport related sectors (vehicle manufacturing, transport operators, transport related services) corresponds to more than 15% of GDP and 10% of employment in EU25. Transport costs and car purchases represent 15-20% of average household consumption, while in some industrial sectors transport costs can reach 30% of total costs. These numbers serve to show the central role of the transportation sector in the European economy.

Transport efficiency
Efficient freight transport is essential for the prosperity of (national) transport operators and logistics service providers. It is therefore crucial for the economy. In turn economic growth increases demand for goods and therefore for their transport: locally, nationally, and internationally. Western-European countries, like the UK, the Netherlands, and the Scandinavian countries emphasise transport efficiency in their transport policy.

Effect of international transport flows
In most countries, models do not explicitly take into account the effect of international flows. Notably transit flows (possibly including transhipment) can be important. National data mostly include the transport to and from the country, and mainly by domestic transport operators. Data on transit flows, especially by cabotage, is regularly incomplete or inconsistent.

The modelling of the effect of these transit flows is consequently complex. The set up of a new international logistics centre in one country can bring economic prosperity, but also causes adverse external effects. In addition, transit traffic that brings low added value to a member state would likely be charged at least for the use of infrastructure.

Safety and security
Almost all member states stress road safety in their transport policy. Countries with a higher number of deaths per million inhabitants than EU average are Portugal, Belgium, Spain, Austria, and Luxembourg.
The tragic attacks in the USA in September 2001 and, more recently, in Madrid in March 2004, have changed forever the context for transport security around the world. From a global and European perspective, supranational regulation and legislation becomes active more and more. Member states must comply with these. In addition, various member states, like Spain, France, and UK, are also developing far-reaching security policies. The sea port of Rotterdam is globally known as a forerunner in port security.

**Analysis of specific sensitive areas**

In the case of special areas such as the Pyrenees, Alps, and Mediterranean basin (MEDA) international cooperation is taking place between countries adjacent to these areas. These special areas usually form an obstacle for transport and in developing policies a joint solution is sought. For example, it is to be prevented that one country blocks the traffic and others will bear the negative effects. Therefore monitoring of Alpine traffic currently takes place.

**Sectorial analysis**

Member states are increasingly worried about the effects of opening the borders within the EU. For example, the number of foreign trucks on the road are an increasing concern. This requires that the nationality of transport is analysed. The information is in most cases available but not yet commonly included in modelling practice. This requires specific tools to be developed.

**Compliance to Commission policies**

In line with the European Transport Policy, most member countries support Motorways of the Sea and inland waterways policies (e.g., RIS, NAIADES, Intermodal Action Programme and MARNIS). Further, in line with TEN-T policy, EU countries make infrastructure investments to upgrade the infrastructure capacity and reliability.

**Growth of freight transport**

A doubling of freight flows by 2050, worldwide, is expected. Within Europe, international flows are growing at twice the rate of domestic flows. This will cause growing freight shares on the roads as growth in passenger traffic is slowing down and freight is moved over longer distances. A further issue is that freight is moved by more and smaller trucks.

**Logistic performance**

The freight logistics sector is customising its products and is creating complex, flexible networks using advanced logistics concepts such as hybrid supply chains, collaborative networks, e-logistics (both business-to-consumers and business-to-business), and return logistics. This will bring about changes in vehicle types HGV/LGV: light vehicle growth figures surpass other categories and appear to be more difficult to capture (both in terms of measurement and public policy). Local environmental damage: new regulations on noise and emissions require more accurate prediction of freight impacts. New technology requires investments. Two further issues are 24-hrs economy and city distribution. The 24-hrs economy leads to different time-space patterns. Firms are spreading production and logistics over day and night with the likelihood that congestion occurs also outside the traditional rush hours. New concepts of city distribution have their impacts on freight traffic flows going into the city (centre). This could have a profound effect on specific streets.
2.3 User Needs in New Member States

This section addresses the user needs of the New Member States (NMS) based on the user need analysis. The main user needs and the major bottlenecks concerning transport modelling in NMS have been identified through interviews (by questionnaires) among model developers and model users and on the base of results of the four workshops (organised in NMS), attended by policy makers and consultants.

The key findings of transport modelling investigated in New Member States can be summarised as follows:

- The models used in NMS are ranging from macro-models (state and region level) through mezzo-models (agglomerations, towns, communities) to micro-models (town parts, crossroads). But, in general, there is focus on regional modelling, not national. However, there are national interests in transport modelling, especially in The Baltic States and modelling of the TEN-T development.

- Transport modelling as the professional tool for a decision-making process is important and the participants of the workshops agreed that it should be promoted in many ways. It was indicated, that transport modelling becomes a higher importance where the public is involved. This forces the policy makers to make well-founded decisions and arguments.

- Uni-modal applications are most common in the transport modelling, but also multimodal models exist, at regional level (mainly regions and agglomerations). In all NMS the following multimodal models are used: private transport (cars) and public transport models (covering all modes of transport) with modal split; traffic models for forecasting modal flows (rail and road); network traffic models to assign traffic flows (road and rail) to the network elements. Specific multimodal models are used in Poland, e.g., demand models for forecasting rail and road transports (freight and passenger) for selected regions and the model covering intermodal and road freight transports modelling between Poland and Germany (on selected routes and for selected goods). There are examples of multimodal models used in The Baltic States: modelling multimodal networks for long-term transport planning (land traffic connections to seaport Tallinn), forecasting transport flows within national transport strategy (Lithuania) and travel demand models for public transport (Latvia).

Transport models applications:

- The models in passenger transport, both car and public transport, are more often developed and used in practice, than freight models, following user needs, expressed especially at regional and local level. The main focus is on modelling passenger transport demands and forecast of passenger traffic flows.

- As far as freight transport modelling is concerned, there are some differences between countries, namely: in Poland and in The Baltic States, freight modelling is used for
international corridors and distribution centres; in Hungary, freight models are used quite rare; in Czech and Slovak Republics, freight transport models are not used at national level. However, Czech and Slovak Republics are very interested in freight transport modelling, especially forecasting freight traffic flows by modes of transport.

- Although all kinds of transport models were assessed as useful, passenger transport models are regarded as more useful than freight transport models.

- All countries, except for Malta and Cyprus, pay a lot of attention to the economic impacts of transport.

Types of models used in NMS:

- In general, there are two groups of models used in NMS: Models that use professional software packages and so-called “own models” developed by the experts for specific user needs. The latter are based on knowledge about economical, statistical and econometric methods of programming.

- The following transport models are mostly used in NMS: transport demand forecast; direct network models to assign traffic flows to the network; impact models on transport infrastructure and policy interventions (using cost-benefit or multi-criterial analysis); socio-economic impact models; road network models; models on traffic distribution in urban network; financial models.

Model developers:

- Typically, professional consultants, from private consulting companies, universities and research institutes develop and operate the transport models in each NMS.

Model users:

- Users of transport models in NMS are mostly the regional and local authorities. However, governmental bodies such as Ministry of Transport, Ministry of Economic Affairs and Communications, Road Administrations are also the users in Hungary and in The Baltic States.

The following user needs have been identified:

- effective analysis of results; reliable software applications;
- ability of applying applications in real time;
- ability of modelling trips by origin/destination matrices;
- reliable and effective tools for public transport modelling;
- complex modelling of transport demand;
advanced tools for assigning traffic flows to transport network;

user friendliness of models.

The main bottlenecks on transport modelling in NMS are as follows:

- The lack of reliable, adequate, and up-to-date information and data is the main barrier and bottleneck in transport modelling. Additionally, there is low availability of high-quality data as well as non-uniform structure of initial data. Solid forecasts of socio-economic data are another quite important barrier.

- Lack of qualified personnel is also regarded in all countries as a main barrier and bottleneck in using and developing transport models.

- Lack of applicable professional software/programmes and lack of resources for purchasing the software.

- Lack of standard types of transport models.

The issues are very different from the EU15 needs. The main reasons for this seems not to be that needs are so different. The two lists answer different questions. The EU15 needs focus on what policy issues need to be addressed. The NMS needs relate more to the needed toolbox to solve policy issues.

Summarising these needs into fewer subject areas results in the following short list;

- Lack of data are mentioned in every country;
- Socio-economic data are important (mainly future data);
- Transport forecasting;
- Need for public transport forecasting;
- Optimisation of public transport;
- Freight modelling (distribution centres, not only corridors);
- Estimation (calibration) of model;
- Transparency of models (no black box);
- GIS systems (compatibility with transport models).

### 2.4 Comparison and structuring of user needs

This section compares the different user needs and structures these into fewer subject areas (see Table 2.2). The importance of each element is ranked from “0” (not mentioned at all), over “+” (Little importance) to “++” (very important). Only issues that were considered important from one of the three user-need groups are included in the table.
<table>
<thead>
<tr>
<th>Dimension</th>
<th>Element</th>
<th>White paper</th>
<th>EU15</th>
<th>New Member States</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Globalisation</td>
<td>+++</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>EU</td>
<td>+++</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>National</td>
<td>++</td>
<td>+++</td>
<td>+</td>
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<tr>
<td></td>
<td>Regional</td>
<td>+</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td></td>
<td>Metropolitan</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
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<tr>
<td></td>
<td>Urban</td>
<td>++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Focus</td>
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<td>+++</td>
<td>+</td>
<td>0</td>
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<td></td>
<td>Strategic (e.g., land use)</td>
<td>++</td>
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<td>+</td>
</tr>
<tr>
<td></td>
<td>Tactical</td>
<td>+</td>
<td>++</td>
<td>++</td>
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<tr>
<td></td>
<td>Operational</td>
<td>+</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td></td>
<td>Optimisation</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Specific modelling areas</td>
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<td>+++</td>
<td>++</td>
<td>+</td>
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<tr>
<td></td>
<td>Changes in trip patterns</td>
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<td>++</td>
<td>0</td>
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<tr>
<td></td>
<td>Mode choice</td>
<td>+++</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Road transport</td>
<td>Identifying Bottlenecks</td>
<td>+++</td>
<td>++</td>
<td>+</td>
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<tr>
<td></td>
<td>Road pricing and fiscal policies</td>
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<td>+++</td>
<td>+++</td>
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<tr>
<td></td>
<td>Road congestion</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
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<tr>
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<td>Competition policies</td>
<td>+++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Capacity and bottlenecks</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
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<tr>
<td></td>
<td>Reliability</td>
<td>+</td>
<td>+++</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Access to outlying areas</td>
<td>+++</td>
<td>+</td>
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<td></td>
<td>High speed rail</td>
<td>+++</td>
<td>++</td>
<td>0</td>
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<td>+</td>
<td>+++</td>
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<tr>
<td></td>
<td>Optimisation</td>
<td>+++</td>
<td>+</td>
<td>++</td>
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<td>+</td>
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</tr>
<tr>
<td></td>
<td>Environment</td>
<td>+++</td>
<td>+</td>
<td>(very mixed interest)</td>
</tr>
<tr>
<td>Inland waterways and short distance shipping</td>
<td>Reinforcement the freight sector</td>
<td>+++</td>
<td>+</td>
<td>(very mixed interest)</td>
</tr>
<tr>
<td>Intermodality</td>
<td>Transport efficiency</td>
<td>+++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Freight transport</td>
<td>Logistics</td>
<td>+++</td>
<td>++</td>
<td>(mixed interest)</td>
</tr>
<tr>
<td>Impact models</td>
<td>Transport safety</td>
<td>+++</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Road safety</td>
<td>+++</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Risk analysis</td>
<td>+++</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Environmental issues</td>
<td>++</td>
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<td></td>
<td>Maintenance</td>
<td>+</td>
<td>+</td>
<td>++</td>
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<td>Cost-benefit analyses</td>
<td>+</td>
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<td>Multi-criteria analyses</td>
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<td></td>
<td>Distributional impacts</td>
<td>+++</td>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>Sustainable transport or sustainable mobility</td>
<td>++</td>
<td>+</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 2.2: Comparison and structuring of the user needs within EC, EU15 and NMS

The table underlines the pattern already noticed that the New Member States focus on models with short time horizon and small geographical scale compared with EU15 and EC. Road transport is seen as central for all actors. Surprisingly evaluation and impact methods are not of interest to NMS according to the figure. This is in contrast with other input on NMS user needs, which has resulted in the inclusion of Chapters 10 and 11.

As the focus of MOTOS is to provide a transport-modelling handbook for the New Member States, the focus should be on the stated user needs in these states. However, as model experiences may be stronger within other application areas, the focus should be broader and draw upon experiences in prior models. It is also worth mentioning, that some of the user needs in the EU15 may arise as needs within a few years in the New Member States and EU15 needs can become needs at EC level. One example here is that reliability of infrastructure networks is now evaluated in the Netherlands, Sweden, and the UK; this might become part of the EC transport policy in the near future. Therefore, the needs in the old member states should not be ignored. Finally, different new (and old) member states have different focus and priorities dependent on the size of the country, geographical location, infrastructure, and actual policy issues.
3 Modelling issues

The purpose of this report is to provide an overview of state of the art and best practice in transport modelling. Therefore, a starting point could be to clarify what is meant by transport modelling. We borrow the following characterisation from Hensher and Button (2000):

"Transport modelling focuses on the ways in which one can simplify and abstract important relationships underlying the provision and use of transport"

This is a very broad description. It underlines that even though MOTOS addresses state of the art in transport modelling, which points in the direction of complex models, the abstract models have to be connected to reality. This implies that data issues and properly handling of results are important aspects of transport modelling.

In relation with the description of transport modelling, it is natural to consider the limits of modelling. A first question that the modeller has to answer before modelling is whether the objective can be fulfilled without a model. This underlines that models should only be build when appropriate and not for the sake of modelling alone. A second question is whether there is an upper complexity level that limits the use of models in practice. This is clearly the case even though the limit changes over time. Furthermore, it should be underlined that many models used in research dealing with complex problems are too complicated for applications due to budget, data, and time constraints.

In this report, we divide transport modelling into four main areas: economic, passenger, freight, and assignment modelling. The areas are neither distinct nor complete. In many cases, they mix in large model complexes. The present chapter describes some general issues concerning transport modelling relevant to all areas of varying degree. This covers model context, the concept of scale, and decision level. Finally, we briefly touch the subject of state of the art versus best practice and transport modelling history.

3.1 Model context

The aim of this project is to describe models from a practical perspective and connect them to best practice. In the jungle of state-of-the-art models, we will therefore concentrate on the models with a clear connection to application.

Central to any applied model is the planning context. This makes the objectives and requirements behind the model very important. Planning is usually a process that starts with an analysis of possible deficiencies of the current transportation system or transport policy. It is followed by a design process that consists of development of a solution, determination of impacts, evaluation of impacts, and analysis of deficiencies. This process continues until a satisfying solution is developed that meets the demand of the planning objectives. An example of planning a new infrastructure project is depicted in Figure 3.1.

The process is often shared between a user and a transport-planning tool. While the planner successively improves the design based on the current state or policy objectives, a computer
model of the transportation system determines future impacts of the solution. The aim of the modelling process is model-based preparation for decision-making.

![Diagram of analysis and design process](image)

**Figure 3.1: Process of planning new infrastructure project**

Gaudry et al. (2001) typifies transport modelling by four elements:

1. Variables: Simple data for a given population, e.g., GNP;
2. Derived indicators: Indicators obtained by combining variables, e.g., CPI;
3. Models: A traditional transport model, e.g., a gravitation model;
4. Derived model results: Results derived from raw model results, e.g., elasticities.

For each element, four dimensions are identified: sample, postulated theory, quantification, and result.

As an illustration, models should consider data, theory, estimation and software, and results. Concerning data, the most important points are data availability, data format, and data quality. Concerning theory, it is important that the model is founded on a sound theory, otherwise interpretation could be difficult and in some cases wrong. On this aspect, it is necessary to point out if a model is representing a calibrated situation or build to capture a cause and effect relationship. The third aspect is estimation both the statistical part and the software part. The last aspect is the output. This can in general be divided into two groups. The first group is where the model output is directly useful as an indicator of some policy. The second group is where the model output is used as input into another model. Then the issue of linking becomes important.
3.2 Geographical scale

This section gives a short overview on issues related to scale. A more in-depth treatment is left for Chapter 12. Traditionally, the transport modelling community differentiates models by the geographical scale of application, i.e.:

- Global models
- European-level models
- National models
- Regional models
- Metropolitan and urban models
- Corridor models

The largest scale is the global scale. Mainly, the relevance of such models concentrates to freight transport, i.e., air- or container networks, but they are seldom used in applied transport models.

Models at European level are gaining in number, but they are still at an early stage. A recent example is TRANS-TOOLS (see TNO, 2005 and TNO, 2006a).

National models are of particular relevance for this report because:

- In smaller countries, such as Lithuania, national modelling aspects are predominately compared to regional aspects due to the size of the country. Therefore, the two main objectives of modelling here are national and urban transport modelling.
- In many countries, the national model and the organisations behind it has been the main driving force in model development. This may include links and coordination to regional models, such as in Sweden and Norway, where the regional models depend on the national models.
- In some regions, transit traffic plays a major role. Therefore, links to national (or even international models) may be crucial in order to describe the traffic within the region.

To separate regional models from national and urban models, we define a regional model as:

- A model covering a region with some unifying characteristics including both urban and rural environments;
- A model covering an area of limited geographical scale making commuting possible, i.e., max 100-150 km;
- A passenger model that focuses on car and public transport;
- A freight model focusing on road transport and goods distribution;
- A model covering a population typically of about 1-5 million people.
The EU NUTS structure cannot be used in the definition, since it is very differently designed from country to country. As an example, NUTS 2 may be used as a regional definition in Germany and the Netherlands, while Denmark is one NUTS 2 only. NUTS 3 on the other hand may be too detailed. In addition, some regions may best be defined as cross-border regions, e.g., the Øresund region of Copenhagen and Malmö.

Metropolitan and urban models cover an urban conglomerate of varying size depending on the city. For instance, congestion and more detailed planning of parking policies, scheduling of public transport, etc., will usually be questions addressed by these models. This category somewhat overlap with regional models, an example could be the models of the congestion charging in London.

Corridor models describe a special class of models. Usually they only include trips of relevance to the corridor making modelling techniques like sample enumeration favourable. Examples of these models are the model for the Great Belt Link in Denmark or the Øresund Bridge between Copenhagen and Malmö.

In some models, it might be reasonable to have several scales. Then a major challenge in the modelling becomes the linking of models of different scales, e.g., when a national model provides through traffic for use within a regional model. This is discussed in more detail in Chapter 12.

### 3.3 Decision level

A traffic model needs to fit into the planning context. In the design of a traffic model, we need to consider level of detail, level of complexity, and time horizon.

Generally, the more time and cost used for collecting data, design, and development of a model the better the description of current traffic conditions. Thus, the level of detail is typically a trade-off between costs for the study and accuracy. On the other hand, detailing a model more than necessary would be a waste of money. Therefore, the level of detail should be targeted to the purpose.

Even a very detailed model in the base situation may fail to describe impacts in the long term. For instance, many traffic models overlook induced traffic despite empirical evidence of the importance of this. This ignorance may be criticised and results even disregarded by decision-makers afterwards. Thus, it is crucial to outline the most likely impacts of the plan proposal and then design the model according to this.

The time horizon is closely related to the level of detail and complexity. In the long run, large infrastructure projects may influence the land-use pattern and economic growth – which again will influence traffic conditions. Thus, the model becomes much more complicated than in the short run.

Figure 3.2 illustrates the relationship between level of detail, level of complexity, and time horizon. The expected level of detail decreases significantly with time, while the complexity
of the model forecast increases. Some interactions between the infrastructure, regional or urban development, and environment may be so complex that it is debatable whether it can be modelled at all. The figure represents a traditional view of good practice guidelines for design of traffic models divided into three categories:

- Operational models only make sense in the short run, as the large uncertainty in the long run makes it unreasonable to conduct operational studies;
- Strategic impacts, on the other hand, may only occur after some time. Therefore, it makes less sense to run these models on short-term conditions;
- Tactical models are usually applied in medium term forecasts (10 to 20 years in the future) based on specific policies and infrastructure proposals.

The three categories of models have different objectives complementing each other. Attempts have been made to develop comprehensive models that deal with operational, tactical, and strategic impacts in both short and long term, but results so far have been rather poor at least from an application point of view.

This report will emphasise models used for evaluation at the tactical level. However, economic models considering strategic levels of decisions and optimisation models at the operational level will be addressed as well.

Figure 3.2: Detail versus time horizon

Figure 3.3 illustrates the land-use transportation feedback cycle. For instance, it illustrates how feedback can operate in a model. The last decision in the transport semi-circle (route choice and assignment) is the most immediate and an operational model in the short run has almost all focus on assignment. The other steps are hardly changed and there is no feedback. This enables very detailed assignment modelling. In the long run, a model at the operational
level changes the input variables marginally, e.g., based on simple trends or forecasts, but there is still no feedback. Examples of operational models are dynamic, road-transport assignment models, simulation models, together with delay and punctuality models for rail.

Most tactical traffic models consider only the supply influence on destination, mode, and route choice. The purpose of using a simple feedback mechanism is that the assignment step can be modelled more detailed. At a strategic level, models focus on the feedback structure between the four steps compromising the level of detail in some of the steps mainly the assignment step. The strategic level centred in the orange part of the Figure 3.3 considers the supply influence on location distribution and activity patterns. Examples are land-use and location models.

![Wegener’s wheel](image)

**Figure 3.3: Wegener’s wheel**

Optimisation could be considered in the evaluation of a proposal. One example is in bi-level problems conditional on transport flows with assignment as lower level. This could be the case if the purpose of the model is to investigate short-term effects from toll charges. Then an upper level would model the supply side considering the toll and the lower level would be an assignment model. This could be solved in a sequential procedure using iterations or simultaneously depending on the size and complexity of the two levels.
A main driver of transport and changes in transport demand is economic activities at different locations. Goods produced in one location are sold in another location and freight transport is required. People live in one location and work in another, where the economic activity is undertaken. This requires commuting. A transport model should be able to use the regional distributed pattern of economic activities to predict consequences of changes in either infrastructure or the regulation of transport through, e.g., taxes, charges or fees. Changes in infrastructure feed back into the economy because goods are cheaper following reductions in transport costs. This has an impact on the activity level in different regions. The interrelation between the regional economic activity and transport demand is dealt with in Chapter 8.

3.4 What is a best practice solution?

In transport modelling, it is common to differentiate between best practice, state-of-the-art, and state-of-practice modelling. Often there is a big gap between state-of-the-art and state-of-practice modelling. Many state-of-the-art models developed at universities have little or no relation to real world applications. In these cases, it is quite natural that practice does not imitate the state of the art. Best practice is inspired by state-of-the-art but closer related to state-of-practice modelling.

Best practice may be a solution between state-of-practice and state-of-the-art. When the conditions for model development, i.e., applications, data availability, budget constraints, etc., are recognised, the best practice solution is, however, often less ambitious than state-of-practice. Therefore, we need to consider the model context and experiences before deciding on best practice solutions. One source for inspiration on the three concepts might be the history of modelling.

The beginning of modern transport modelling dates back to the 50s and 60s with early developments of models for highway appraisal. The models were aggregated models and evolved into the four-step pattern that is still the backbone of most demand models today. The use of aggregated models was challenged in the 70s where new ways of data collection and the development of discrete choice models in econometrics lead to the use of disaggregate models. The disaggregate models has become the state-of-practice, whereas different mixes of aggregate/disaggregate models still are most common in applications. The last 10 years have also lead to the implementation of activity-based models. These are still at an early stage and still rare in applications. See Bates (2000) for further discussion of this history.
4 Transport modelling methodology

This chapter provides a summary of common methods used in transport modelling. For a more comprehensive discussion the reader is referred to, e.g., Ben-Akiva and Lerman (1985), Sheffi (1985), Hensher (2001), Cascetta (2001), and Ortúzar and Willumsen (2001). Some of the issues are rather technical. The basics on these issues can be found in the references above.

A main contribution from microeconomic theory to transport modelling is the framework of supply and demand together with the concept of equilibrium (Figure 4.1). Transport models should consider both supply and demand but of course, the degree of detail is context-dependent. A central point is that models are estimated or calibrated on equilibriums hence a forecast should also predict an equilibrium. In practice, this is done by iterative procedures and it highlights the importance of model convergence.

In the next section, we describe the demand aspect of transportation. In the second section, we describe the ideas behind supply and assignment. Then we introduce estimation, calibration, and validation procedures in the two following sections. The last section is devoted to a general discussion about application of the estimated and validated model.

![Figure 4.1: Demand and supply crossing in equilibrium](image)

### 4.1 Demand

Demand is in many cases the cornerstone of travel analysis. Three features are important to remember when thinking of transportation demand. Demand is in general derived, it has a spatial dimension, and it is dynamic. In applications mainly the spatial dimension has been recognised. However, if important the two other aspects should be incorporated as well.

The demand will be either continuous, e.g., tonnes of goods, or discrete, e.g., number of trips. Continuous data can be described by linear regression and related models, e.g., generalised
linear regression. The second kind of outcome has lead to much research in transport modelling. Two main approaches to modelling this kind of variables are discrete choice models and entropy models. The role of the different model types can be seen in relation with the three classic steps of demand modelling, i.e., generation, distribution, and modal split. The generation step has no standard model type. Though generation often has discrete outcomes, two common approach are growth models and linear regression models. The distribution step is in many applications done by a gravity model or similar entropy approaches. The discrete choice models have mainly been developed and used in the modal split step. Note that both discrete choice models and gravity models can be used to build entire transport models, though this has not been state-of-practice.

4.1.1 Continuous variable models
The most important model in applied statistics is the linear regression model. It also has many applications in transport modelling. Suppose that $Y$ is a continuous random variable and that $X$ is a k-dimensional random variable. The model is then

$$ Y = \beta'X + \varepsilon, $$

where $\varepsilon$ is a continuous random variable. A standard assumption is that $\varepsilon$ is normally distributed independent of $X$. The use of the model in transportation modelling is both common when $Y$ is continuous, e.g., when forecasting income, or when $Y$ is to be assumed approximately continuous at an aggregate level. The model can be generalised to incorporate non-linearity in $Y$, e.g., generalised linear regression.

Even simpler models are often useful such as prognosis models. One example is when the value of travel time (VoT) is forecasted based on GDP. If a base VoT is known a future VoT can be forecast using the observation that the elasticity of VoT with respect to GDP is somewhere between 0.5 and 1.

4.1.2 Entropy models
The term entropy model covers models based on an entropy function. The most used entropy model in travel demand is the gravity model. The double constraint gravitation model should be preferred if origin and destination totals, i.e., $O_i$ and $D_j$, are known. Suppose that $T_{ij}$ is the count from origin $i$ to destination $j$. Let $a$, $b$ be constants and $d_{ij}$ be resistance between $i$ and $j$, then the model assumes that

$$ T_{ij} = a_i b_j f(d_{ij}) $$

where $\sum_{j \in D} T_{ij} = O_i$ \hspace{1cm} (4.1)

and $\sum_{i \in O} T_{ij} = D_j$

under conditions
A general functional form for \( f \) is

\[
\sum_{i \in O} O_i = \sum_{j \in D} D_j, \\
D_j > 0, \\
O_i > 0, \\
f(d_{ij}) > 0.
\]

This specification has both the exponential and the power function as special cases. The double constraint model can be used for estimation of parameters and missing flows, updating of matrices and prediction for future matrices. In the case of unknown totals the model becomes unconstraint and can only be used for estimation of parameters and missing flows. Another entropy model worth mentioning is described in the next section. The MNL model can be deduced as an entropy model.

It is important to note that entropy models base themselves on the assumption that all micro states are equally probable. This is only realistic in homogenous populations and might not be true when travellers have different purposes or choice sets.

### 4.1.3 Discrete choice models

A common approach in transport modelling to describe discrete choices is the notion of utility. The utility theory enters when the modeller assumes that the travel behaviour is based on travellers or firms maximising their utility in a given context. The traveller/consumer is assumed to have a latent utility function

\[
U = U(x,p),
\]

where \( x \) are continuous goods and \( p \) are prices. In transport modelling, it is common to incorporate travel times \( t \) in utility or to incorporate the time aspect through generalised costs.

In applications, data seldom follows the deterministic predictions made by utility theory. A more useful model is obtained by adding a random component. In the case of discrete choice models, the random utility maximisation (RUM) model is normally expressed as

\[
U_i = V_i + \varepsilon_i, \quad (4.2)
\]
where $\varepsilon_i$ are random variables. The simplest model is the linear in parameters model

$$U_i = \beta' x_i + \varepsilon_i,$$

where $x$ are explanatory variables of alternative $i$, and $\beta$ are coefficients to be estimated. If the $\beta$ varies in the population one should use a model allowing for heterogeneity, i.e., allowing different segments to have different parameters.

Utility theory is sometimes criticised for being to simplistic and unrealistic. However, it is still the only behavioural theory working in large model complexes. Furthermore, it forms the basis for transport appraisal, e.g., CBA. The central assumption in discrete choice models consistent with RUM is that the alternative with the highest utility is chosen. Therefore, the probability of choosing alternative $i$ for a given choice set $C$ and conditional on explanatory variables $x$ is

$$P(i \in C \mid x) = P(U_i > U_j, \forall j \neq i \mid x).$$

From equation (4.2), it is seen that the probability depends on the specification of $V$ and the distributional assumptions on $\varepsilon$. The three central families of models are generalised extreme value (GEV), probit, and mixed logit models.

To facilitate the presentation of the three families we will assume that the specification of $V$ is chosen to be linear in parameters, i.e.,

$$U_i = \beta' x_i + \varepsilon_i,$$  \hspace{1cm} (4.3)

where $\varepsilon_i$ in all models are assumed independent of $x_i$.

The GEV family assumes that $\varepsilon$ follows a GEV distribution. The simplest case, the multinomial logit (MNL) model, assumes that the $\varepsilon_i$ are independent of one another. This leads to the following probabilities

$$P(i \in C \mid x) = \frac{e^{\psi_i}}{\sum e^{\psi_j}}.$$  

A more complicated GEV model assumes that $C$ is partitioned into mutually exclusive groups (nests) and that the error terms are correlated within each group but not across groups. This leads to the nested logit model with probabilities

$$P(i \in C \mid x) = P(i \in A_m \mid x)P(m \in M \mid x),$$

where the first factor in the product is the probability of choosing the alternative $i$ in nest $m$, and the second factor is the probability of choosing nest $m$ among the possible nests and both
of the factors have a MNL structure. Note that the notation hides how the logsum over the alternatives in a nest enters as an explanatory variable in the MNL model for nest choice.

The idea of nesting can be developed further to overlapping nest and more levels. This leads to the most general GEV model used in applications, the network GEV. The strength of the GEV models is that they are very fast to estimate. Furthermore, the more general models overcome some of the problems with the simple MNL like independence of irrelevant alternatives. A weakness is that they are homoscedastic, i.e., the variance of $U_i$ is constant in the population. Furthermore, the more complicated models with many nest coefficients sometimes have identification problems with these coefficients in estimation.

The multinomial probit (MNP) model has the same simple appeal as the GEV models. The specification is also very similar. A MNP model assumes that $\varepsilon_i$ follows a normal distribution. In the simple case the normal distributions are independent for each alternative. In the general case they can have any pattern of correlation under the restriction that only $J(J-1)/2$ coefficients can be identified, where $J$ is the number of alternatives. The strength of the MNP models is the intuitive appeal by which correlation between alternatives can be handled. But it is slower to estimate than GEV models and it has the same problem with identification if too many correlation coefficients are estimated.

The final family is the mixed logit (ML). A ML model assumes that the $\beta$s in (4.3) follow some distribution in the population. This is a very flexible model family. It allow for heteroscedasticity (the variance of $U_i$ varies in the population) and serial correlation between a sequence of choices. The great difficulty and danger with the model is the choice of distribution on the $\beta$s. Therefore, the use of this model should only be done after careful investigation of possible distributions and specification of the deterministic part of utility.

Examples of heteroscedastic models and flexible structure models (including mixed logit models) are given by Bhat (2000) and Koppelman and Sethi (2000). The theoretical derivation of these models is well-documented in the literature (Luce, 1959; McFadden, 1981; Ben-Akiva and Lerman, 1985; Anderson et al., 1992; Hensher and Johnson, 1981; Horowitz et al., 1986; Bierlaire, 1998; Ben-Akiva and Bierlaire, 1999).

The close connection between discrete choice models, transportation, and economic theory is exemplified in the goods-leisure model by McFadden and Train (1978) and in the overview by Daly (2006).

One of the many useful applications of discrete choice models is the estimation of the value of time (VoT), see Section 5.6.4. Suppose one has a mode choice model with alternative 1 being car and alternative 2 being public transport. Then a simple model would be

$$U_i = \alpha_i + \beta_i^T x_{Ti} + \beta^C x_{Ci} + \varepsilon_i,$$

where $\alpha_i$ are the alternative specific constants of which one has to be normalised, the $\beta_i^T$ are mode specific marginal utilities of time and $\beta^C$ is the marginal utility of cost. From microeconomic theory it can be derived that
\[ VoT_i = \frac{\partial V}{\partial T_i} \frac{\partial T_i}{\partial C}. \]

So based on the model above VoT in the two modes would be

\[ VoT_i = \frac{\beta_i^c}{\beta^c}. \]

### 4.2 Supply

The purpose of supply in a transport model is to reflect the way in which costs of travel vary according to usage of particular facilities, e.g., a highway or a train. As usage rises costs generally rise as well, typified by the congestion that occurs as a road or turning movement approaches capacity. The supply - often referred to as level-of-service (LoS) – is an integral part of the assignment stage of the transport modelling process.

Assignment models compute LoS information to demand models, enable spatially detailed analyses, and provide information for operational, environmental, economic and financial appraisals. The relative importance varies according to the requirements of the study. For instance, at a strategic level the main need is for a cost generator.

Assignment models can vary considerably depending on objectives and design of the transport model. However, common to all assignment models are: a computerised representation of the network, a mechanism to calculate viable routes through the network, a mechanism for loading origin-destination (OD) demand onto the routes, and a mechanism ensuring that supply and demand are in some sort of equilibrium at the end of the assignment process.

Important features of road traffic assignment models are capacity restraint, multi-routing, and equilibrium seen as the fulfilment of Wardrop’s First Principle, which states that under equilibrium conditions no driver can reduce generalised cost by changing route. Typically, capacity restraint is represented by highway link-based speed/flow relationships. In urban environments, capacity restraint affected by junction delays ought to be considered by explicit modelling of junctions, taking account of physical turning capacities, signal timing and the interaction of conflicting traffic movements. Multiple time periods can also be an important feature of assignment models and generally representations of peak and off-peak periods are required to model congestion impacts.

Important features that need to be considered when designing public transport assignment models are network representation, sub-modal choice, multi-routing, and capacity restraint. Public transport networks are typified by links, lines, and timetables. Link-based representation involves an aggregated representation of public transport services coded onto highway and rail network link definitions. Disaggregate coding of bus and rail lines explicit onto the network provides the best basis for representing public transport LoS and routing opportunities. Line services may either be represented by some sort of aggregation or detailed
timetables. The latter requires an initial high effort with respect to service coding unless automatic procedures may be deployed to generate the networks from operators time schedules.

Sub-mode choice can be carried out as part of the route choice process within the assignment, or as part of the overall demand model hierarchy. Multi-routing is important, in particular in urban environment, where there are a number of viable alternative passenger paths - e.g., parallel rail routes or bus rail competition. In practice, models usually ignore the potential impacts of crowding upon route choice due to complexity and huge run times.

Typically, state-of-practice freight models are adapted versions of assignment procedures applied in passenger transport. Time and cost structures are different in freight transport from passenger transport requiring other generalised cost functions and route choice behaviour. For instance, transhipment and distribution are important features, which need to be considered in freight routing and calculation of LoS. Freight transport is governed by many rules and laws, e.g., dwell times and heavy competition between operators, making it difficult to gain access to cost and service information for network representation.

### 4.3 Estimation and calibration procedures

General procedures for estimation and calibration are presented below. Estimation consists of fitting a model using uncertainty to explain the data. Calibration can be seen as fitting a model in an iterative procedure to data using the number of parameters necessary to reproduce the data sufficiently.

Before estimation or calibration of any model, it is important to assure identification. A simple example of no identification is the case of co-linear variables in linear regression or a full set of alternative specific constants in a discrete choice model.

#### 4.3.1 Estimation methods

We will describe three estimation approaches Maximum Likelihood Estimation (MLE), Ordinary Least Squares (OLS), and maximum entropy.

Suppose a model gives probabilities $P(y|\beta)$ depending on unknown parameters $\beta$. MLE consists of estimating the parameters as the arguments that maximise the log likelihood (LL) function

$$LL = \sum_n \log P(y_n | \beta, x_n).$$

The resulting estimator is consistent and asymptotically normal.

Suppose we have a linear regression model. The standard way to estimate the parameters is OLS. For a linear regression this gives the estimates
The resulting estimator is once again consistent and asymptotically normal. It is more robust than the MLE against misspecifications. In regression models, the goodness of fit is usually expressed by the mean squared error ($R^2$), which is determined by:

$$R^2 = 1 - \frac{\text{residual sum of squares}}{\text{total sum of squares}}.$$ 

$R^2$ takes a value between 0 and 1. The closer this measure is to 1, the better the fit. There are some difficulties related to the use of the $R^2$ goodness of fit measure and there are some ways of adjusting it.

A related problem is time-series estimation. A basic time-series (multiple regression) model includes relations of the following type:

$$Y_t = \alpha_t \mathbf{X}_t + \varepsilon_t,$$

where $\alpha$ are parameters of the model and $\varepsilon$ is a random variable with a normal distribution. There may be many explanatory variables, $\mathbf{X}$, and thus many parameters (or elasticities) to be estimated in these models. The parameters are estimated using ordinary least squares (OLS), when a set of basic assumptions are fulfilled. The assumptions are then checked after the model has been estimated.

1. The disturbance term has a mean equal to zero
2. The disturbance term has constant variance, which is uncorrelated across observations
3. The disturbance term is not explained by the explanatory variables
4. The explanatory variables, $\mathbf{X}$ are non-stochastic
5. The disturbance term follows a normal distribution with mean 0.

The parameters or coefficient can be tested for different hypothesis, e.g., whether a specific parameter has a specific value (typically zero) or a hypothesis involving more than one coefficient. The hypothesis testing is further used to test which of several model specifications performs best. Comparing the overall model fit is an indicator of this. The hypothesis testing of the general non-linear models is done using the Likelihood ratio test or using the Lagrange multiplier test, based on the decrease in the sum of squared residuals that would result if restrictions on the model are released. Detailed descriptions and the specific use of the different tests can be found in for example Davidson and MacKinnon (2003).

A last estimation method that we will describe is the Furness algorithm, which can be used when estimating new trip matrices based on old patterns. It is an example of maximum entropy estimation.

The algorithm is described in Ortúzar and Willumsen (2001), p. 168-170. We will use the same notation.
$T^*: $ Initial solution

$T^*_j$: Final solution

$O_i$: Row totals

$D_j$: Column totals

The algorithm is based on the following equation

$$T_{ij} = T^*_i a_i b_j ,$$

where $a_i$ and $b_j$ represent correction terms and $T^*_i$ corresponds to $f(d_{ij})$ in the gravity model on p. 31. Furthermore, we have two constraints

$$\sum_i T_{ij} = D_j$$

and

$$\sum_j T_{ij} = O_i .$$

The algorithm has the following steps

Step 1: Set $b_j = 1$ and solve for $a_i$. Hence, $a_i = O_i / \sum_j T^*_j$.

Step 2: With $a_i$ from the previous step, solve for $b_j$. Hence, $b_j = D_j / \sum_i T^*_i a_i$.

Step 3: With $b_j$ from the previous step, solve for $a_i$. Hence, $a_i = O_i / \sum_j T^*_j b_j$.

Step 4: If changes are sufficiently small then stop. Otherwise, go to step 2.

For all the above methods, standard software is available.

4.3.2 Calibration issues

Calibration is an iterative procedure where model output is fitted to match observed data and an important part in any applied transport model. Even after ambitious estimation, travel demand models may fail to replicate various observations on the real world transport system. For instance, this may be the case for certain aggregated travel volumes or link flows. This is the reason why calibration of travel demand models often takes place.

There are basically three related approaches, which are used in such efforts:
Adjust the constants of the models or introduce specific adjustment factors in order to increase the agreement with observed data.

Calibrate the network and zone connectors in order to fit modelled traffic to counted traffic.

Substitute or complement model estimation by more or less advanced heuristic procedures used in fitting the model to observations.

The first approach is used in most demand modelling contexts, e.g., when nested logit models are estimated on survey data and other aggregate data are available. With a large number of adjustment factors, it is easy to produce a good result. However, there is no explanation to the adjustments and in a forecasting situation, these factors are taken to be constant over time. Ortúzar and Willumsen (2001) caution on the use of a large number of so-called K-factors in aggregate travel demand modelling.

Network calibration is conducted based on results from the assignment. If the network information, for instance, is based on general road maps, etc., local speed limits might not be available. In the calibration, the network can then be adjusted directly by an inventory of local conditions or indirectly through adjustments until counts and output fit. A divergence between modelled and counted traffic may also come from incorrect zone connectors or too large zones loading traffic to the network in an inappropriate way.

It is important to note that calibration is not an exact science. It relies on experience to know what kind of precision to expect from a given model type. Furthermore, calibration should not be used to cover over errors in other parts of the model. Given a problem, it is important through validation to detect the source of differences between predictions and observations before adjustment.

4.4 Validation

Validation is the process of quality control, in this case applied to implementations of transport demand modelling. By validating a model system one attempts to judge the credibility of the forecasts to be produced by the system. This is not an easy task and it is often somewhat neglected in practice.

Thorough validation of a model or model system could involve several steps. The following scheme might serve as a checklist for analysing how well a system functions and how well it serves its purposes:

- **Practical validation:** The first step should be to make sure that the system is correctly modelled (system limitations, exogenous and endogenous variables, policy handles, appropriate for intended use, etc). Are the necessary resources available and is the model complexity required for answering the questions from model users?
- **Theoretical validation:** The next step is related to the theoretical foundations for the methodology: equilibrium or disequilibrium, static or dynamic, degree of integration of sub-models, are casual relationships reasonable and well modelled? This step aims at a quality control before the model is implemented and applied.
Internal validation: This step focuses on the result of the estimation and calibration. Does the model reproduce input data with a reasonable goodness of fit without relying on too many adjustment factors? Are the parameters of the right sign and statistically significant? Is the responsiveness to changes in explanatory variables defendable (as revealed by sensitivity tests or implied elasticities)?

External validation: This final step deals with the forecasting ability of the model in real applications. Can the model reproduce other data than those that are used for its estimation and calibration (e.g., traffic counts on road links)? Are the elasticities of the model compatible with the majority of other studies in the literature? Can the model foresee the impacts of a certain policy package? The ultimate test of the forecasting ability can only be analysed if before-and-after data related to a policy package are available. Such external validation is very rare, as is systematic comparison of alternative models in one and the same spatial context.

Ideally, validation should be conducted based on a sample not used for the estimation or calibration. However, due to time restrictions this is rarely possible. The validation sample is most often a representative sub-sample, which was not used for the estimation and calibration of the model. The outcomes predicted by the model on the validation sample are then compared to the actual outcomes for the validation sample.

In general, validation can also be divided into formal and informal tests. Informal tests consist of comparing expectations on signs or relative sizes of parameters. It is also useful to compare VoT estimates or demand elasticities with those reported by other studies. An example of a more formal test is the percent root mean square of the error used to assess whether modelled traffic approximates counts sufficiently. Other examples can be found in, e.g., Vuk and Hansen (2006).

There is no fixed procedure for evaluating economic models. Validation also crucially depends on the type of model. Macro-economic models predicting future development of a national economy should be able to describe the main trends accurately, whereas some strategic models should be accurate only in relative terms. For example to indicate which of several effects that are likely to be the most important consequence of a new policy. This type of results is the most common in economic modelling. The models provide answers as relative changes in key variables, i.e., with less focus on absolute values. This is particularly the case in SCGE modelling even though some CGE models are developed to answer absolute questions as well.

The best validation of the model is to use it for several purposes, to be careful interpreting the results, and to compare them to other similar studies. Are the results within an expected range of values and do the output look similar to the results of other models?

4.5 Application

When models are used to analyse a policy issue or investment, they are tested on different scenarios. In this case, it is necessary to forecast certain background variables whereas the patterns represented by the base model are most often assumed stable over time. Since most models are estimated on cross sections this is the only possibility. Two possible scenarios are
the “do something” and the “do minimum” scenarios. They are seen in Figure 4.2, where A is the base scenario, B the “do something” scenario, and C is the “do minimum” scenario. It is important to realise that the generalised cost will change between the scenarios. Therefore, it could affect the forecast whether generalised cost is measured in time or money units. Furthermore, it is important how VoT is forecasted.

![Figure 4.2: Forecasted demand and scenarios](image)

In a scenario, it is necessary to decide on how uncertainty is handled. The largest amount of uncertainty in forecasting arises from derived data and the possible instability of patterns in the base scenario. There are many other sources, but in practice, they seem to have a smaller effect. Some are:

- Measurement errors in data;
- Imprecise network data;
- Self-selection bias in reported data;
- Statistical uncertainty;
- Computational uncertainty in either simulation or optimisation;
- Model specification, e.g., omitted variable bias or the fact that the model does not capture causal relationships correctly;
- Uncertainty due to solution algorithm;
- Aggregation error and transfer error.

For some of these sources methods exist to quantify the uncertainty, e.g., imputation for data uncertainty, Monte Carlo simulation, bootstrapping to understand estimator uncertainty, and robust estimation to minimise the effect of specification errors.

In relation to uncertainty in model output, it is relevant to note that total uncertainty has another component, which is termed variability. It is important to bear in mind that the modeller can only work on reducing uncertainty, but not variability inherent in a transportation system.
A often used approach to reduce uncertainty in forecasting is to apply pivot-pointing of demand matrices. It minimises the errors by focusing on changes relative to a base. Two reasons why changes relative to a base might give more precise forecasts are that base year demand matrices obtained from observations (counts, surveys, etc.) usually have more accuracy and that errors in a model can cancel out when only proportions are modelled.

We will not discuss all different approaches: factorial, incremental, or additive pivoting. For most purposes, the factor pivot-point method is adequate. The procedure applies the ratio of model outputs for base and forecast situations as a growth factor to the base matrix, i.e., in a given cell the predicted number of trips $P$ is given by

$$P = B \cdot \frac{S_f}{S_b},$$

where:

$B = \text{observed base year trips from the base matrices}$

$S_b = \text{base year synthetic trips}$

$S_f = \text{future year synthetic trips}$

Two important questions are then how to deal with zero cells and extreme growth. Table 4.1 shows an example of how to deal with this.

<table>
<thead>
<tr>
<th>B</th>
<th>$S_b$</th>
<th>$S_f$</th>
<th>Growth factor</th>
<th>rule</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 0$</td>
<td>$\leq 0$</td>
<td>$\leq 0$</td>
<td>Max($0, B + (S_f - S_b)$)</td>
<td>$0$</td>
<td></td>
</tr>
<tr>
<td>$\leq 0$</td>
<td>$&gt; 0$</td>
<td>$\leq 0$</td>
<td>Max($0, B + (S_f - S_b)$)</td>
<td>$S_f$</td>
<td></td>
</tr>
<tr>
<td>$&gt; 0$</td>
<td>$\leq 0$</td>
<td>$&gt; 0$</td>
<td>Normal</td>
<td>Max($0, B + (S_f - S_b)$)</td>
<td>$0$</td>
</tr>
<tr>
<td>$&gt; 0$</td>
<td>$&gt; 0$</td>
<td>Normal</td>
<td>Max($0, B + (S_f - S_b)$)</td>
<td>$S_f - S_b$</td>
<td></td>
</tr>
<tr>
<td>$&gt; 0$</td>
<td>$\leq 0$</td>
<td>$&gt; 0$</td>
<td>Extreme</td>
<td>Avg. growth $\times B$</td>
<td>Avg. $\times B$</td>
</tr>
<tr>
<td>$&gt; 0$</td>
<td>$&gt; 0$</td>
<td>Extreme</td>
<td>Max($0, B + (S_f - S_b)$)</td>
<td>$B + S_f$</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1: Pivot-point table for matrix adjustment

As the table indicates, the modeller needs to decide on what is meant by extreme growth before applying the rules. This can be based on statistical arguments but needs also to take into account local conditions in the study area.
5 Data in transport modelling

There is a mutual relationship between model and data. On one hand, data needs depend on the nature of the model. On the other hand, design of the model must reflect available data sources. Therefore, the base of a model is the quality and amount of available data, and strictly speaking, no model is better than the data it is founded on.

In the modelling process, data may be considered in terms of use:

- For building causal relationships;
- For disaggregation of other data or results;
- For validation, and
- For forecasting.

Since costs for new data collections often are quite high, it is important before designing the model to review existing data sources. Therefore, an inventory of existing data should always be conducted in the initial phase of the model development as a base for model design and to estimate the need for new data collections.

Based on Williams (2002) data sources to support modelling can be considered under seven broad headings as illustrated in Table 5.1. It can be used as a guideline for an inventory of existing data source (Williams, 2002 and Hansen, 2003), though in practice there will exist overlaps between the types of data. Based on the categorisation in Table 5.1, Section 5.1-7 introduces some important existing data sources the modeller should be aware of when developing a traffic model. While some source may relate mostly to passenger models, other may primarily support freight models or economic models.

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Land-use data</td>
<td>Population, employment, car ownership</td>
</tr>
<tr>
<td>2. Economic/financial data</td>
<td>Account data, costs</td>
</tr>
<tr>
<td>3. Network data</td>
<td>GIS based roadmap</td>
</tr>
<tr>
<td>4. Statistics</td>
<td>Trade, freight transport statistics</td>
</tr>
<tr>
<td>5. Demand surveys</td>
<td>OD patterns, traffic counts</td>
</tr>
<tr>
<td>6. Behavioural data</td>
<td>Household survey, value of travel time studies</td>
</tr>
<tr>
<td>7. Operational data</td>
<td>Logistics relationships</td>
</tr>
</tbody>
</table>

Table 5.1: General data needs

Table 5.1 differentiates between statistics and data surveys. While statistics are a continuing registration of more general and public available data, surveys are ad-hoc based registrations with a specific objective. For instance, surveys are used to collect demand data (e.g., origin-destination patterns and traffic counts) and behavioural data (e.g., household survey and stated preference experiments). Typically, demand data are used to construct trip matrices, calibration, and validation of the model, whereas behavioural data are used to estimate causal relationships in the model. In addition, the data collection methods are often quite different.
for the two types of data. Therefore, demand surveys and behavioural data are categorised separately in Table 5.1.

Depending on data availability, model requirements, and budget constraints, it may be decided to collect new data. Some issues to consider are whether it is necessary to have panel data or whether cross section data are sufficient and whether it is necessary to have disaggregate data or aggregate data are sufficient. Furthermore, the need for stated preference (SP) data and revealed preference (RP) data must be discussed. The choice of new data often reflects a compromise between two conflicting objectives: accuracy and cost, since data collection is usually quite expensive. A new data collection can be characterised by sample size, questionnaire, and strategy. The first item clearly depends on the balance between accuracy and cost. The second item should assure that the actual data are obtained and the third item how they are collected. The strategy has to include which sampling to use. The two common ways to sample is either to obtain a simple random sample or to stratify on either a background variable, e.g., area, or a dependent variable, e.g., travel mode. Section 5.8 discusses data collection methods from a theoretical and practice perspective.

Section 5.9 is devoted to a discussion of data merging and deriving data from other data sources. A cost efficient approach to gather sufficient data for modelling purpose may be to merge data sources. Care must be taken to variations in definition of data items, segmentations, data foundation, year, etc., resulting in often quite complicated procedures of data merging (e.g., Polak et. al, 2006 and Nielsen et al., 2006).

5.1 Land-use data

Land-use data are categorised into the following broad groups:

- Classification of areas of land without further identification of intensity of use or development (zoning).
- Quantities associated with land use, usually in the form of statistical values for zones, e.g., population, employment.
- Gazetteer data that list properties, addresses, or items such that their position is known. Sometimes, additional information is available with gazetteer entries, for instance the type of use of a property at an address.

5.1.1 Zoning system

A zoning system is used to aggregate the individual households and premises into manageable chunks for modelling purposes. The first choice in establishing a zoning system is to define the study area itself from the rest of the world. Some ideas may help in making this choice:

- In choosing the study area one must consider the decision-making context, the schemes to be modelled, and the nature of the trips of interest, mandatory, optional, long or short distance, and so on.
- For strategic studies one would like to define the study area so that the majority of the trips have their origin and destination inside it; however, this may not be possible for
the analysis of transport problems in smaller urban areas where the majority of the trips of interest are through-trips and a bypass is to be considered.

- Similar problems arise with traffic management studies in local areas where again, most of the trips will have their origin, destination, or both clearly outside the area of interest. What matters in these cases is whether it is possible to model changes to these trips arising as a result of new schemes.
- The study area should be somewhat bigger than the specific area of interest covering the schemes to be considered. Opportunities for re-routing, changes in destination and so on, must be allowed for.

To build a model the study area has to be split in homogenous model zones in their land-use composition. A zone should represent the natural catchment area of the transport networks. The zoning system should also be compatible with other administrative divisions, particularly with census zones, to ease the use of census data in modelling and forecasting.

The two main dimensions of a zoning system are the number of zones and their size. The greater the number of zones, the more detailed and accurate the modelling will be. However, it requires that sufficient data is available and with suitable spatial disaggregation. Other concerns are model objectives and computing time, which often increases by the square of number of zones. The choice of zoning system is closely connected with the geographical scale discussed in Section 3.2.

5.1.2 Land-use data

Census data are used extensively as a basis for person trips models, but less so for freight. The main elements of data, which are relevant are:

- Population by sex, age classes (0-4, 5-9, ..., 65-70, > 70), and income;
- Employment by category, e.g., agriculture, industry, office, and retail;
- Car ownership;
- GDP by, e.g., agriculture, fishery, forestry, industry, and services;
- Households by size, income.

In passenger models, the most important data are related to population and employment. It explains the generation and attraction of trips. The economic data often provide a good indication for freight transport patterns. For example, the production and attraction of chemical products is at best explained by the size of the chemical sector in as well the region of export as the region of import. A common feature of economic models is the inclusion of a labour market. Some models focus on how commuting is affected by regulation in the labour market and other models focus on how the labour market is affected by regulation on passenger transport. This requires specific knowledge of the labour force composition.

In economic models, it is necessary to know the income in different regions and in different industries to develop the model and specify levels and relative differences in the models. For other models, household or personal income is explicitly used to determine other variables such as vehicle ownership or estimate causal relationships, e.g., mode choice.
While land-use data sources differ in some respects between countries, population census is usually available in rather disaggregated form from national databases. When GIS is applied to census data, it is possible to extract data on a user-specified zonal system with respect to data confidentially, of course. Other international, national, and local databases (or zip codes) may also be available and used to build a zonal database for the specific model purpose.

The modeller should also be aware of the growing availability of data from private firms. Prominent companies that publish catalogues of such data include ESRI, CACI, Geoplan, Kingswood and MapInfo. However, some data are less complete than transport modellers would like. Thus, it is necessary to understand quality of any data source before using it.

In forecasting, future socio-economic developments must be gathered and estimated. These developments correspond to a specified scenario. Ideally, use can be made of national forecast of, e.g., population and employment. Additionally, it can be discussed with the client or local authorities.

5.1.3 Gazetteer data
National Land and Property database and Zipcode Address Files are examples of gazetteer data. The National Land and Property gazetteer contains every address in the country with unique property reference number and a grid coordinate reference. The potential value for modelling lies in its aim to link other data sources (land-use data, postcard data, etc.) to the zonal system of the model.

The Zipcode Address File is a master list of addresses for postal operations. In UK for instance, it has become the most widely used address list and provides accurate grid reference for each address. A derived product, Code-Point, gives the mean grid reference of each zipcode. This has value in coding transport surveys.

5.2 Economic/financial data
Common for most economic data is that they are in monetary terms. It is important to focus on whether the economic value is measured in annual values (prices) or in fixed prices using a specific base year. Annual prices include inflation and will often lead to mistaken indication of relationships with other variables that are similarly measured in annual values. To avoid this it is necessary to use a fixed base year where inflation is removed from the values. This is done using, for instance, index theory (e.g., the Passche index or the Laspeyes index) or national statistics.

Economic and financial data discussed below include:

- National accounts and input-output tables;
- Regional and firm account data;
- Price and tax data;
- Travel cost data.
While input-output tables and account data are used mainly for economic models, it is necessary for all models to have reliable information on the operating costs facing suppliers of transport, and on tariffs charged to the users of these services.

5.2.1 National account data and input-output tables
There has been a long tradition for economic models and economic data collection in the EU countries. Hence, economic data are generally available in a consistent and coherent way through a rather long time period. Data are collected at both national level and international level through, e.g., Eurostat and OECD. Most data are complete accounts and not based on sample studies, etc. An input-output table includes monetary flows between suppliers and demand. It describes relationships between import, production, and usage and is compiled from the national account data usually by the national statistic offices.

Traditionally, economic models are non-spatial. An example is models of second-best pricing of transport infrastructure (Verhoef, 1996, contains a number of examples). These describe two links between two locations and assume figures that can illustrate the problem analysed. This is also the aggregation level normally employed in the national accounts published by the different national statistical offices. However, it is necessary to include a spatial disaggregation to give an operational description of transport, especially for the two types of economic models that are linked to passenger or freight transport. This often requires a rather huge amount of resources, which may be prohibitively expensive. An example of spatial disaggregation of input-output tables by use of detailed trade data is the Danish model SAM-K at municipality level (Madsen et al., 2001).

Another problem in the national accounts is that the internal transport undertaken by companies owning their own vehicles and private transport in cars are not directly visible. The transport activities are indirectly accounted for through, e.g., the businesses’ and private households’ purchase of vehicles and vehicle fuel. In some countries (e.g., the Netherlands and the UK) almost half of the new car sales are company cars. To find these vehicles and their monetary flows in standard statistical sources is not easy (Korver et al., 2006). Creating satellite accounts of transport is an approach to deal with the missing data on transport activities. Satellite accounts use other sources of information to calculate, e.g., the amount of private transport in private cars. One important element in the satellite accounts is that the overall values are consistent with the values in the national accounting system. Unfortunately, creating satellite accounts are standard practice in very few countries (Johnsson, 2003, for Sweden and Fang et al., 1998, for the US).

Problems also arise in transport modelling due to the inherent differences between categories that are of most relevance and those of most relevance to economy as a whole. The classification of economic sectors in the national accounts does not correspond to the commodity classification (e.g., NST/R). This is not easily resolved.

5.2.2 Regional and firm accounts data
Economic data at the regional level are not always available and they are most often not part of the data publication made by the national statistical offices. It is also often the case that they are not compiled in a way that is usable for transport modelling. This means that regional
data must be constructed independently based on the official aggregate data in combination with various other (incomplete) data sources.

Firms are in many countries required to send account data to tax and custom authorities. Often the national statistics office then compiles and publishes the data on an aggregated level, e.g., county level.

5.2.3 Price and tax data

Prices are in most economic models the factor that ensures equilibrium between supply and demand. Price changes or price differences determine changes in demand and supply of commodities, services, etc.

A large number of prices are needed for economic modelling. The price of transport is necessary for many applications. Especially in models where the specific price level is an important model output. Transport prices must be known at the level of detail used in the model. It is necessary to know the price or relative levels of different modes, if individual modes are explicitly modelled. Typical prices used in economic models are:

- Housing prices;
- Wages;
- Public transport prices (possibly differentiated on different modes);
- Private car prices (purchase prices and prices on the use of cars);
- Freight transport costs.

Another set of relevant prices are values for non-market goods; - externalities and public goods. Such values are used in evaluation models, but are also relevant in any other model, e.g., to analyse changes in welfare.

Taxes, tolls, and fees are often the policy variable that is being investigated in economic models. It is often necessary to know the level of these variables and the revenues they generate to have the correct starting point for the analysis of alternative tax scenarios. Many models, especially equilibrium type of models, specifically include calculations of the government (or any other tax collecting institution) spending. For this purpose it is necessary to know tax levels of all relevant taxes, tolls, and fees. Examples are:

- Income tax levels;
- Value added tax levels;
- Commodity-specific tolls or taxes;
- Registration taxes, ownership taxes;
- Commuting allowances;
- Tax on company cars;
- Existing transport taxes (e.g., Eurovignette);
- Subsidies for labour, public transport, and other subsidies.
5.2.4 Travel cost data

In passenger transport, information on travel costs per mode is necessary. Usually travel costs may be generated from official statistics and fare tables. In many countries, information on passenger car driving costs by cost type is annually published. Since public transport fares often decrease relative by distance, are based on a zonal system, are differentiated by day and travel groups, etc., it may be necessary to use approximations in modelling. In particular, costs by air line services are complicated to include in passenger models due to low cost air lines and great daily variations.

Goods vehicle costs are critically dependent on vehicle utilisation since if utilisation increases, fixed costs are spread more widely. Costs have been driven down over recent years by increasing utilisation and this is particularly the case for large logistics operators who are able to achieve economies of scale.

Collection of cost data for other modes of freight transport is usually confidential information of transport companies. Due to the liberalisation of transport sectors, firms are very reluctant to render this information (notably in railway transport, firms are becoming more reluctant compared to the situation where most of them were state owned). To cope with this new situation in UK, for instance, a price of freight services is provided by the Corporate Services Price Index (CSPI) published on the internet. This site publishes time series from 1995 of indices of prices for road freight, commercial vehicle ferries, sea and coastal waterborne freight, freight forwarding, and parcel and courier services.

5.3 Network data

The purpose of modelling networks are multiple, e.g., assigning trips and presentation of results. Traditionally, transport-modelling projects have assembled network data in a relative crude manner. With a growing attention to congestion and reliability, more accurate and detailed network modelling is required. Below, network data are discussed divided into:

- Road networks;
- Bus and rail services;
- Ferry and other waterborne transport;
- Air line services.

5.3.1 Road networks

When building a road network the modeller should make use of existing sources (for example national road databases in GIS). Road maps of existing models may be used and combined to cover the area of interest depending on the level of detail required. For instance, the GIS-based road network created in the process of developing the TRANS-TOOLS model could be used as basis for national transport models.

Recently, road maps as GIS layer from commercial suppliers have become available. For instance, detailed network data files from suppliers of in-car navigation data, such as Navtech, are available. Nationally, a number of different road maps often are commercial available, in
Denmark for instance, three different suppliers (DAV, Top10, and KRAK) provide detailed GIS-based road maps.

While costs of the road map of course play a major role in the decision of which to select and apply in modelling, the decision should also include:

- The number and detail of attribute data. At least the following attribute data should be considered: distance, free flow speed, link type, and capacity (usually in passenger car equivalent units (PCU) per hour).
- The spatial resolution. In some model application, mapping of major roads may be sufficient whereas other studies may require more details. Another concern is that road maps with sufficient detail facilitate combination with other GIS layers.
- Connection to other data sources. The combination and use of related data sources is easier if the road map includes predefined ID connections.
- The updating frequency. In forecasting, it is an advantage if the GIS-based network is frequently updated. This reduces the manual coding of roads opened after the base year.

5.3.2 Bus and rail services

Modelling bus and rail transport networks are more complex than road networks. A public transport network consists of:

- Links (road or rail links); It is important to have a relation, for instance, between bus services and the road network to pre-load buses to be considered in calculation of road congestion;
- Stops; A GIS layer of all stop nodes in the network;
- Lines; A sequence of stop making up the line of service;
- Timetable; Database with departure/arrival time and travel time linked to the stop layer and line description.

The modeller has to decide to which extend details should be included in the public transport network. Until recently, the public transport was usually assembled quite crude based on line and timetable approximations, e.g., service aggregated over time periods. The developments of computer sciences, however, have today made it feasible to apply a more realistic timetable-based network modelling in large-scale models.

In building the network, it is valuable to look for digital information from local and national train and bus companies. In many of the European cities, for instance, bus and rail timetables are used to develop a public itinerary on the internet. It can be downloaded and used for modelling purposes (e.g., Nielsen et al., 2006). Timetables for international rail services are available from, e.g., HAFAS, Planco, however, it may be necessary to do some checking and transformations before using these.

In TRANS-TOOLS, a simple rail network has been developed based on GISCO in the version of TEN-STAC originating from the UIC network. It includes link length, travel time, and approximated service frequency.
The rail freight network differs from the passenger rail network, since some parts of the network is only used for passenger transport. Thus, in the TRANS-TOOLS separate networks for passenger and freight are developed. The rail freight transport consists of scheduled and non-scheduled services. While it is difficult to collect information about the scheduled services due to a large number of operators and confidentiality, it is almost impossible to picture the non-scheduled rail services. Therefore, in practice, most rail freight network modelling relies on approximations and assumptions.

5.3.3 Ferry and other waterborne transport
Information about ferry lines services is available from the ferry companies. Since ferry lines are included in many traffic models, an easier way could be to collect information from existing models. In the TRANS-TOOLS model, a large number of ferry lines are included, though some need to be updated.

Lloyds Maritime Information Service (LMIS) hosts a large database with information on ship movements. This can be used for coding of a maritime transport network. The work, however, is substantial and in the TRANS-TOOLS model, it was decided not to develop networks for maritime transport.

Network modelling of inland waterways are often not included in freight transport models except for certain countries (e.g., Netherlands, Germany) where it has a large impacts on freight transport flows. The TRANS-TOOLS model includes an inland waterways network based on GISCO in the version of TEN-STAC.

5.3.4 Airline services
Today, information about passenger airline services is available from the internet. However, it requires much manual work to code air line services for a larger area, e.g., Europe due to the many different suppliers. For instance, the passenger airline network in the TRANS-TOOLS model originates from GISCO. Since many new air services and low-cost providers were not included in the GISCO-network, it was decided to do some updating based on information from different sources, especially the internet. Although a large effort was put into the work, it was impossible within the timeframe of the project to carry out a complete update.

It is like rail freight transport difficult to gather information about airfreight services. However, airfreight services only play a minor role in freight transport and carry a small load of goods, and in many cases, it is actually done by road. Thus, the airfreight network is usually disregarded in freight modelling.

5.4 Statistics
We define statistics as a regular registration of more general data, which are usually collected and published by the national or international statistics offices. Below some of the most important statistics used for transport modelling are considered:
Trade statistics;  
Freight transport statistics;  
Passenger transport statistics;  
Commuter statistics.

5.4.1 Trade statistics

Since trade is the origin of all transport movements, as transport is a derived demand from trade relations, these data are the basis for freight and economic models. A general approach on how and what such models should include is contained in, e.g., Steininger (2001).

Preferably, the trade statistics should contain information about:

- Origin (region, country);  
- Destination (region, country);  
- Commodities;  
- Modes (at the national border, EU border, at origin, at destination);  
- Containerisation;  
- Weight;  
- Value;  
- Route information, e.g., border crossing, transhipment sea ports, or transhipment other terminal(s).

Trade describes the relation between origin and destination by commodity type (e.g., SITC, CN). Transhipment locations (sea ports and other terminal(s)) and border crossings refer to information with respect to the logistic and transport choices made in planning the transport of goods from origin to destination.

The variables should be collected in as much detail as possible. The ideal situation would be if all information needed to describe transport would be available from the trade registrations. Unfortunately, this is not expected to be found. It should be attempted to get as close as possible to the ideal situation. Usually contacts should be established with the central bureau of statistics as they usually gather more detailed information than they report. Elements like region-to-region information or transhipment locations are unfortunately only available in very limited and/or fragmented cases. The following sources may be considered:

- National trade data for all core countries;  
- CEPII;  
- ETIS-BASE;  
- EUROSTAT COMEXT;  
- UN trade data.

Trade statistics are usually provided in tonnes and monetary units. Depending on the use in freight or economic modelling, tonnes or money may be preferred. A conversion from, e.g., money flow to tonnes, however, is complicated and needs thorough considerations.
The national trade data reveals often divergence between import and export between the statistics of two countries. Therefore, international databases are preferred at country level because of a consistency.

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<th>Trade data</th>
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<td>Sources</td>
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| Table 5.2: Overview of available trade data within the EU |
| * Mode and transhipment information is known for UK trade with countries outside the EU. |

The CEPII\(^2\) has constructed a database called CHELEM. It consists of three sub-databases that make it possible to analyse the relative positions of individual countries and their interdependence within the global economy. The whole CHELEM database is distributed on CD-ROM and online. CEPII, however, only includes money flows, and commodity

classification is not linked directly to other common classification systems

In the NEAC model and in the ETIS-BASE data, for instance, country-to-country data have been used from the COMEXT database since this is consistent for all EU countries. Region-to-country trade data from national sources is then used to include the regional detail.

5.4.2 Freight transport statistics

Trade data describe the movement of goods between countries or regions, whereas transport statistics describe the movement of transport units (vehicles, containers etc.) at specific locations (ports, ferry, terminals, etc.). Transport data are often used for validation of the transport model and disaggregation of other data sources, e.g. regional transport information can be used to estimate regional trade patterns. In this process, differences between the data sources need considerations. For instance, trade statistics use net weight, whereas gross weights are used in transport statistics. The gross weight in transport statistics may include the weight of container or swap body.

In freight statistics, it is convenient to differentiate between international transport, domestic, transport, and loading units flows. Table 5.3 includes a list of international transport data sources whereas Table 5.4 lists domestic transport data.

After 1992 the availability and quality of trade and transport data has decreased or the data are not available anymore (information about ports and modes have become optional for intra-EU flows in the Intrastat system).

Currently EUROSTAT collects port-to-port data from the member states according to the Maritime Directive (see, "Council directive 95/64/EC of 8 December 1995 on statistical returns in respect of carriage of goods and passengers by sea"). The data contain no information about transhipment, but it does contain information about goods loaded and unloaded in ports in relation with partner ports (combined with trade information the transhipment can be determined).

Several sources provide the information about the individual terminals in Europe: the INTERMODA (an FP5 project) database on terminal data in Eastern Europe, the information from the UIRR (International Union of combined Road-Rail transport companies), and ICF (Intercontainer-Interfrigo) information (rail terminals Western Europe, http://www.uirr.com/ and www.icfonline.com).

Not only data are needed about vehicle movements (transport data) or the movements of the commodities in them (trade data) but also information on the containers is of interest. Containers can have different origins and destinations than the commodities in them and the vehicles transporting them. These data therefore are of at least comparable value for the ETIS reference database. An example of such data sources is the Piers database that describes the movements of containers between USA and Europe where multiple transhipments are included. It could be important to make a distinction between filled and empty containers. Some container data sources are EUROSTAT, COMEXT (container indicator, only for extra-EU trade), UIRR, ICF, Piers database, Ports, and Inland terminals.
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<th>Sources</th>
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<th>Country to country</th>
<th>Region to region</th>
<th>By region</th>
<th>Transport mode</th>
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</tr>
</tbody>
</table>

Table 5.3: Overview of available international transport data
Table 5.4: Overview of available domestic transport data

5.4.3 Passenger transport statistics
Nationally and internationally, a number of statistics are available and relevant for passenger transport modelling. It varies from country to country in number and detail, thus, the national databases need closer examination before initiating the modelling process. Some typical relevant passenger transport statistics are:

- Sale and ownership of motor vehicles, motorcycles, etc.;
- Passenger statistics by public transport (passenger km, boardings, etc.);
- Non-scheduled passenger transport (taxi and coach services);
- Vehicle km.
5.4.4 Commuter statistics
Some national statistics offices combine statistics of home address information with other statistics containing information about work relations and workplaces to produce commuter statistics. Commuter statistics describe the spatial relation between home and workplace aggregated into some catchments areas due to confidentiality. The catchments areas are administrative units or predefined zones based on GIS analyses.

Commuter statistics are useful in passenger transport modelling as basis, e.g., for OD matrices. However, they cannot directly be applied to transport modelling, since they do not capture mode of transport. Second, flexible jobbing and variations in work locations, e.g., tradesman are not considered in the commuter statistics.

5.5 Demand surveys
To obtain information on the broad spatial pattern of freight and passenger transport surveys are conducted, some on a need to known basis others more regularly. Data are used for a wide range of modelling task, for instance, examination and construction of travel patterns, calibration and validation. Existing data sources include:

- Road traffic counts;
- Roadside surveys;
- Public transport counts;
- Public transport surveys;
- OD data.

5.5.1 Road traffic counts
For estimation, calibration, or validation of a traffic model, it is necessary to have a number of traffic counts (cars, passengers) throughout the study area. The effects of daily variation, misclassification, and survey error are often underestimated, but when conducted properly, comprehensive series of classified counts are valuable.

In many countries, the state and local authorities organise this. At many sites on the highway network, traffic is permanently measured per hour and/or day (cars and trucks separately). Figure 5.1 shows the counting sites at highways in the region Amsterdam-Rotterdam in the Netherlands. In practice, traffic counts will be gathered from different sources (e.g., manual counts, automatic counts), different time periods and maybe different years. It is therefore necessary to adjust the count data to a common reference, e.g., AADT and year.

Counts are also used in estimation of OD matrices. In the calibration process, the quality of the count information is important. Therefore, not all counts should have the same priority. The reliability of a count depends on several elements, for instance, length of counting period, year, vehicle classification, and equipment (loop detectors, rubber tubes). The UN/ECE collects every 5 years from all European countries the road count data, the last was for 2005.
5.5.2 Roadside surveys
Traditionally, roadside surveys are common in transportation studies and modelling. An inventory of existing roadside surveys is, therefore, good practice before any modelling tasks. Often both cars and commercial vehicles are intercepted, and the latter are distinguished by vehicle type. Interviews are necessarily brief, in order to avoid traffic problems at the site and to maintain a reasonable sample rate. Since intercepting traffic at motorways is complicated and often risky, this may bias roadside surveys.

A common problem with roadside interviews is that, as they generally only operate for 12 or 16 hours, they obtain a biased sample of goods vehicles, in particular, because during night time the majority of movements are trunk haul, while during the day the majority are distribution. Other problems with roadside interview data for freight models are, e.g., that information about goods commodity being carried is seldom collected, and trip legs are collected rather than tours.

5.5.3 Public transport counts
Passenger counts are necessary for validation and estimation of passenger traffic models, but they are not standard procedure like road traffic counts. A wide spectrum of technologies are used, which include manual sample counts, automatic passenger count systems, fare box data, GPS, etc. Before use, the quality of data should be evaluated. For instance, operators conducting counts as basis for revenues sharing may be biased.
Passenger counts are also used for estimation of OD matrices for public transport. Due to the nature of more complexity and insufficient data, this is in practice done less frequently than for road transport. A recent example is described in Nielsen et al. (2006).

5.5.4 Public transport passenger surveys
Passenger surveys are generally conducted using one of the following techniques or combinations of techniques:

- On-board interviews and counts;
- At stop/station interviews and counts;
- Self completion questionnaires.

Passenger surveys provide information about the spatial travel pattern, and they are, in particular, useful in estimation of OD matrices. Data may be collected in, e.g., metropolitan areas and by major railway operators. However, in a competitive and liberalised marked passenger surveys are often more or less confidential and not public available.

5.5.5 OD data
Data from existing models are an important data source in development of new transport models. OD data from existing models seldom fit the new requirements exactly due to differences in zonal structure, trip purposes, commodity classifications, base year etc. However, it could be a good starting point for estimation of new OD matrices based on count data.

Few large surveys are conducted with the objective to estimate the spatial flow pattern of goods or passengers. An example is the Swedish Goods Flows Survey (CFS) conducted in 2001 (SIKA, 2001).

5.6 Behavioural data
The main sources are household data and travel diaries. In more advanced travel studies, GIS data supplement the diaries. Many European countries collect this kind of data in national travel surveys. There are other types of behavioural data, and below the following data are discussed:

- Household travel surveys;
- RP data surveys;
- SP data surveys;
- Value-of-travel-time (VoT) studies and other willingness-to-pay (WTP) studies;
- Elasticities in passenger and freight models;
- Elasticities in economic models.

5.6.1 Household travel surveys
Data needs for estimation of conventional trip-based or tour-based passenger demand models include household travel surveys with trip diaries in addition to data defining activities and transport systems. Household travel surveys provide household and individual socio-
economic data (e.g., income, household size, and car ownership), travel-activity data (e.g., 24-hour diary of travel activities (purpose, destination, mode, and timing)) and household vehicle data.

Travel surveys give a lot of information about the travel patterns on a regional or national scale like number of trips per day per mode, average trip lengths and modal split. Several statistics can be extracted, which can be used for the building and validation of the passenger model. For example, the average number of daily trips per person in the Netherlands for five urbanisation categories is shown in Table 5.5 (Mobiliteitsonderzoek, 2005).

<table>
<thead>
<tr>
<th>Urbanisation Category</th>
<th>Car driver</th>
<th>Car passenger</th>
<th>Train</th>
<th>Bus/tram/metro</th>
<th>Moped</th>
<th>Bicycle</th>
<th>Walking</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very strongly urban</td>
<td>0.69</td>
<td>0.38</td>
<td>0.09</td>
<td>0.24</td>
<td>0.02</td>
<td>0.68</td>
<td>0.66</td>
<td>0.03</td>
<td>2.80</td>
</tr>
<tr>
<td>Strongly urban</td>
<td>0.95</td>
<td>0.46</td>
<td>0.07</td>
<td>0.07</td>
<td>0.03</td>
<td>0.79</td>
<td>0.58</td>
<td>0.04</td>
<td>2.99</td>
</tr>
<tr>
<td>Moderately urban</td>
<td>1.07</td>
<td>0.52</td>
<td>0.06</td>
<td>0.03</td>
<td>0.03</td>
<td>0.84</td>
<td>0.51</td>
<td>0.05</td>
<td>3.11</td>
</tr>
<tr>
<td>Less urban</td>
<td>1.04</td>
<td>0.52</td>
<td>0.03</td>
<td>0.05</td>
<td>0.02</td>
<td>0.85</td>
<td>0.50</td>
<td>0.05</td>
<td>3.04</td>
</tr>
<tr>
<td>Not urban</td>
<td>1.06</td>
<td>0.52</td>
<td>0.03</td>
<td>0.04</td>
<td>0.02</td>
<td>0.81</td>
<td>0.53</td>
<td>0.05</td>
<td>3.06</td>
</tr>
</tbody>
</table>

Table 5.5: Average number of daily trips per person

It can be concluded that the total average number of trips increases by decreasing urbanisation and that there are big differences between modes. The share of public transport is very high in strongly urbanised areas but is lower for less urbanised areas. It is the other way around for trips made by car.

Figure 5.2 (Mobiliteitsonderzoek, 2005) shows the relative daily trip length frequency per person for the modes car, train and bus/tram/metro. The figure illustrates that the number of trips by car decreases by increasing travel distance, while a relatively small amount of trips by train are made over short distances and the frequency is increasing by distance.

![Relative trip length frequency per person per day](image)

Figure 5.2: Relative trip length frequency per person per day

The data needs for activity-based models are generally more extensive than for conventional travel demand models. Full activity diaries are required with information from households...
and individuals on activity type, start and end time, location, travel mode, travel time, accompanying persons, planned or unplanned activity, etc. Additional data are needed for the location of facilities where activities can be carried out, on institutional constraints like opening hours and on the transport system.

Household travel surveys are normally the responsibility of regional or national authorities, either occasionally or as ongoing activities during some time period. For example, the Swedish SAMPERS model system (including national and regional models) was estimated on the national Swedish travel survey 1994-98, containing 30,000 interviews for the entire period. On the other hand the most recent regional travel survey of the Stockholm region was conducted in 1986/87. The updating of the Dutch national model in the late 1990s was based on household travel surveys from 1995 containing 68,000 interviews, currently the number of interviews has been reduced to 50,000.

In a number of countries, a yearly national household travel survey has been conducted, at least during some time periods (United Kingdom, Germany, Sweden, Denmark, the Netherlands). These national surveys can also allow regions to obtain their own household travel surveys (e.g., in Stockholm, Copenhagen and Amsterdam) by increasing the sample size in order to provide a more detailed and improved basis for regional modelling.

5.6.2 Revealed preference data surveys
Revealed preference (RP) data provide useful additional information about trips not registered in household surveys (i.e., external-external trips in a cordon survey). RP surveys are often collected by roadside surveys, passenger surveys, or postcard analyses as discussed in Sections 5.5.2 and 5.5.4 and include at least information about origin, destination, mode, and trip purpose. Often a RP data survey is carried out before a stated preference survey to obtain a list of respondents.

5.6.3 Stated preference surveys
Collection of stated preference (SP) data by game experiments is a well-known and well-established technique today. It consists of observations were individuals have been asked to make abstract choices. In general SP is a complement to RP data. SP data has the advantages that

- New modes can be taken into consideration;
- Many questions can be obtained at low cost;
- Correlation can be controlled.

These exactly correspond to the disadvantages of RP data. On the other hand, SP data has to be carefully specified to avoid unrealistic alternatives, policy bias and justification bias. Furthermore, SP results should in most cases be calibrated against RP data.

It is common to distinguish between within- and across-mode games. Within-mode games can be used to estimate mode specific VoT (e.g., Table 5.8), whereas across-mode games are useful demand elasticities between modes.
5.6.4 Value of travel time studies

Some other examples of SP experiments are value-of-time studies. Marginal external costs are analysed in the large EU project ExternE. Krewit (2002) reviews the 10-year long experience gained from ExternE in 2002. The results from this study are used in many countries as the basis for catalogues of prices to be used in, e.g., cost-benefit analysis.

There is a vast amount of information about marginal external costs. Many countries have undertaken their own studies on various types of external costs. The value of travel time savings (VoT) is perhaps the external cost that in relation to transport is the most investigated. Tables 5.6 and 5.7 show examples from Netherlands:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Work</th>
<th>Business</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>8.48</td>
<td>29.36</td>
<td>5.86</td>
</tr>
<tr>
<td>Train</td>
<td>8.54</td>
<td>18.07</td>
<td>5.27</td>
</tr>
<tr>
<td>Bus/tram/metro</td>
<td>7.95</td>
<td>13.86</td>
<td>5.03</td>
</tr>
</tbody>
</table>

Table 5.6: VoT in the Netherlands (in €/hour, situation 2006)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Work</th>
<th>Business</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>9.48</td>
<td>32.83</td>
<td>6.54</td>
</tr>
<tr>
<td>Train</td>
<td>9.54</td>
<td>20.20</td>
<td>5.89</td>
</tr>
<tr>
<td>Bus/tram/metro</td>
<td>8.89</td>
<td>15.49</td>
<td>5.62</td>
</tr>
</tbody>
</table>

Table 5.7: VoT in the Netherlands (in €/hour, situation 2020)

The travel time of public transport is the sum of access time (from origin to first stop), waiting time, in-vehicle time, transfer time, number of transfers, egress time (from last stop to destination). Not all of these times weight equally for a passenger. An example of weighting factors is shown in Table 5.8:

<table>
<thead>
<tr>
<th>Time components</th>
<th>Weighting factor</th>
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</thead>
<tbody>
<tr>
<td>Pre-transport time</td>
<td>2.3</td>
</tr>
<tr>
<td>Waiting time</td>
<td>1.6</td>
</tr>
<tr>
<td>In-vehicle time</td>
<td>1.0</td>
</tr>
<tr>
<td>Transfer time</td>
<td>1.2</td>
</tr>
<tr>
<td>Number of transfers</td>
<td>8.2 (penalty in minutes)</td>
</tr>
<tr>
<td>After-transport time</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 5.8: Weighting factors public transport

The state-of-practice approach to estimate VoT is based on disaggregated data, usually a combination of household or other RP data and SP data.

Recent years have seen numerous studies around Europe and still new studies are under way. One example is the VoT study from Denmark (Lyk-Jensen et al., 2006). In addition, many other cost components have been investigated. Not all studies have resulted in “official” values contained in, e.g., a catalogue of recommended values. Other examples of official publications of marginal external costs can be found in among others Danish Ministry of Transport and Energy (2006), which is updated annually. When the values are not contained in such catalogues or other official publications, uncertainty and disagreement is often the
outcome. Any value can be chosen for any specific study. In some circumstances, it may be acceptable to choose values different from the official ones, but it is then necessary to consider why the chosen values are not in line with the recommended values. This is a real strength of the official lists of values. Another argument in favour is that, e.g., the cost benefit ratios of different projects are comparable because identical prices and methods are used.

5.6.5 Elasticities in freight and passenger models

Elasticities are used for validation of models to test the sensitivity compared to other similar studies found in literature, etc. In simple freight and passenger models, elasticities may be directly applied in the formulations, however, generally this is not good practice since it has no theoretical foundation. Goodwin et al. (2004) and Graham and Glaister (2004) contain recent reviews of estimated direct price elasticities from a large number of studies detailing different modes, freight and passenger transport, etc. However, cross-price elasticities or substitution elasticities are not equally well analysed and it is very difficult to obtain relevant values without initiating new studies aimed at estimating the elasticities needed.

5.6.6 Elasticities in economic models

A typical economic model specifies demand and production functions for a number of commodities. The functional form depends on more than the immediate commodity being modelled. Production functions for example use a number of different intermediate inputs and factor inputs (labour and capital). The production function specifies the trade-off between the different inputs. The elasticities specify the degree of sensitivity of the demand for the varying input factors. It is necessary to know how much demand for one type of input increases when the price of another input changes (the cross-price elasticity).

Estimation of substitution elasticities is the topic for many economic models and analyses, but a large number of economic models depend on the availability of substitution elasticities from other studies. The most common substitution elasticities are

- Substitution between factor input and intermediate inputs;
- Substitution between labour and capital;
- Substitution between different intermediate inputs;
- Substitution between different types of commodities;
- Substitution between labour supply and leisure.

Another equally important set of elasticities consists of income elasticities. These specify demand changes when income changes.

5.7 Operational data

For some model types, particularly those that attempt to bring logistical processes into considerations, it is necessary to consider the availability of data about freight operations. Sometimes such information can be used in form of single parameter values, but in other cases it will be more appropriate to use distributions of the characteristics. Some examples of operational data are:
Tonne conversion factors to convert commodity flow values to weight;
Shipment sizes to commodity and vehicles class;
Carrier characteristics by commodity type;
Operator behaviour relationships (e.g., working hours, dwell time);
Terminal and transhipment locations;
Occupancy rates for conversion from person to passenger vehicles.

In freight modelling, such data can come from standard surveys such as the Continuing Survey of Road Goods Transport (CSRGT) or contact with operators. If data are needed more extensively, it is necessary to define the characteristics to be identified and to establish the mechanisms for obtaining them.

A specific element of operational data is terminal and transhipment locations. These are difficult to identify on a comprehensive basis, and require considerable work with operators to establish the important locations.

In passenger models, it may be necessary to convert number of persons to vehicles before assignment. An example of present and expected future occupancy rates is shown for a Dutch study in Table 5.9.

<table>
<thead>
<tr>
<th>Year</th>
<th>Trip purpose</th>
<th>Work</th>
<th>Business</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td></td>
<td>1.14</td>
<td>1.11</td>
<td>1.50</td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td>1.12</td>
<td>1.09</td>
<td>1.39</td>
</tr>
</tbody>
</table>

Table 5.9: Occupancy rates car

### 5.8 Data collection methods

#### 5.8.1 Sampling techniques

Sampling has many advantages compared to a complete census. First, if data are secured from only a small fraction of the aggregate, expenditures are smaller. Second, surveys that rely on sampling have more scope and flexibility regarding the types of information that can be obtained. Third, the data can be collected and summarised more quickly with a sample than with a complete count. Fourth, a complete census may be impracticable due to, e.g., a very large population.

On the other hand, results of sample surveys are always subject to some uncertainty because only part of the population has been measured and because of errors of measurement. The word population is used to denote the aggregate from which the sample is chosen, for instance, households or cars. Before selecting the sample, the population must be divided into parts that are called sampling units, or units. These units must cover the whole population and they must not overlap, in the sense that every element in the population belongs to one and only one unit. The construction of a list of sampling units, called a frame, can be a practical problem. In transport modelling, for instance, a frame of persons to participate in SP experiments may be constructed from a postcard survey in the area of interest.
A sample survey is a practical business that calls for several different types of skill, and poor performance in one phase may ruin a survey in which everything else is done well. The purpose of sampling theory is to make sampling more efficient. It attempts to develop methods of sample selection and of estimation that provide, at the lowest possible cost, estimates that are precise for our purpose.

Random sampling is the dominant strategy of selecting units from the population. In simple random sampling, the units has an equal chance of selection in the population. In a sample survey we decide on certain properties that we attempt to measure and record for every unit that comes into the sample. These properties of the units are referred to as items.

If the population consists of N units and the random sample of n units, the values for the units in the sample are denoted $y_1, y_2, \ldots, y_n$. The sample mean, e.g., average number of trips per day per adult is

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$$  \hspace{1cm} (5.1)

The variance of the estimated mean are used primarily for three purposes: to compare the precision obtained by simple random sampling with that given by other methods, to estimate the sample size needed in a survey, and to estimate the precision actually attained in a survey that has been completed. Usually the population variance is not known, but it can be then estimated from the sample data;

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{n} (y_i - \bar{y})^2$$  \hspace{1cm} (5.2)

The standard error of the estimated sample variance is the squared root of (5.2). To estimate the sample size needed in the survey, an estimate of variance often has to be based on older or similar data. When the sample has been collected and data processed a more accurate variance can be estimated.

The estimates of the variance of the mean value is

$$\sigma^2 = \frac{1}{n} \left( \frac{s^2}{y} \right)$$  \hspace{1cm} (5.3)

where $f = n/N$ is the sampling fraction. We obtain from Equation (5.3) that the variance (uncertainty), e.g., of the average number of trips, can be reduced by taking larger samples. In a large population, the finite population corrections can be ignored, since $n/N$ remains low and the corrections factor close to unity. For instance, if the standard error is the same in two populations, a sample of 500 from a population of 200,000 gives almost as precise an estimate of the population mean as a sample of 500 from a population of 10,000.
It is usually assumed that the estimate of the mean is normally distributed about the corresponding population values. If the assumption holds, lower and upper confidence limits for the population mean are

\[ \hat{Y} = \bar{y} \pm z \frac{s}{\sqrt{n}} \sqrt{1 - f}. \]  

(5.4)

The symbol \( z \) is the value of the normal deviate corresponding to the desired confidence probability. For instance, \( z = 1.96 \) using a confidence probability of 95%.

In sample survey, it is necessary to consider biases for two reasons. First, in some common applications, particularly in the estimation of ratios, estimators are found to be biased. Second, errors of measurements and non-response may produce biases in the averages that we are able to compute from the data. This happens, for instance, if the persons who refuse to be interviewed are almost all opposed to use public transport, whereas those who are interviewed are split evenly between using public transport and car. In order to incorporate the bias and compare with unbiased estimators, the mean square error (MSE) is useful. Formally,

\[ \text{MSE} \left( \bar{y} \right) = v(\bar{y}) + (\text{bias})^2. \]  

(5.5)

In planning of a sample survey, a decision must be made about the sample size. Too large a sample implies a waste of resources, and too small a sample diminish the utility of the results. Stratified sampling is a common technique to gain precision in the estimates, and hence, reduce costs to data collection.

In stratified sampling the population of \( N \) units is divided into subpopulations of \( N_1, N_2, \ldots, N_H \) units, respectively. These subpopulations, called strata, are non-overlapping, and together they comprise the whole of the population. To obtain the full benefit from stratification, the values of \( N_h \) must be known. When the strata have been determined, a sample is drawn from each, the drawings being made independently in different strata. The sample sizes within the strata are denoted by \( n_1, n_2, \ldots, n_H \). If a simple random sample is taken in each stratum, the whole procedure is described as stratified random sampling.

For the population mean per unit, the estimate used in stratified sampling is

\[ \bar{y}_s = \frac{1}{N} \sum_{h=1}^{H} N_h \bar{y}_h = \sum_{h=1}^{H} W_h \bar{y}_h, \]  

(5.6)

where \( N = N_1 + N_2 + \ldots + N_H \). The estimate of the sample mean is

\[ \bar{y} = \frac{1}{n} \sum_{h=1}^{H} n_h \bar{y}_h. \]  

(5.7)
It is not in general the same as the population mean. The difference is that in \( y_{it} \) the estimates from the individual strata receive their correct weight \( N_h/N \). If the samples are drawn independently in different strata,

\[
v(\hat{y}_{it}) = \sum_{h=1}^{H} W_h^2 v(\hat{y}_h) = \sum_{h=1}^{H} W_h^2 \frac{S_h^2}{n_h} (1 - f_h).
\] (5.8)

In the allocation of samples to strata, one should, in general, take a larger sample if the stratum is larger, the stratum is more variable internally, and sampling is cheaper in the stratum. If the cost per unit is the same in all strata, the optimum allocation for a fixed sample size is the one which minimizes the variance. In this case, the optimum value of \( n_h \) is

\[
n_h = n \frac{W_h s_h}{\sum_{h=1}^{H} W_h s_h} = n \frac{N_h s_h}{\sum_{h=1}^{H} N_h s_h}.
\] (5.9)

5.8.2 Case study
Before a new data collection is conducted, the modeller should always carry out an inventory of existing data sources due to the high cost of data collection. When it has been decided to obtain new data for modelling, planning of the new data collection is required. In general, data collection is performed in a number of successive steps starting with a formulation of objectives and ending with data analysis. Figure 5.3 illustrates an example of a systematic approach to collection of new data.

Below the process of new data collection is illustrated by a roadside survey. Let us say, that we have to develop a transport model for a metropolitan area. Based on some existing data sources, we are in the position to develop a model for travel behaviour within the metropolitan area, whereas our information about trips to and from the area and through the area is incomplete. Therefore, we decide to conduct a new data collection. While information about passenger travel pattern by rail and bus is evaluated to be sufficient, the objective of the survey is to estimate vehicle movements with origin or destination in the survey area and vehicle movements through the survey areas. Therefore, we decide to conduct a roadside survey.

Because the interview needs to be brief, not more than 30 seconds, questions should be targeted to the purpose. In passenger transport, the questionnaire includes questions about origin, destination, home address and trip purpose. At the same time, the interviewer enters information about interview time, type of vehicle, and car occupancy. Typically, truck drivers are asked about, e.g., origin, destination, commodity type (few classes) and total weight of the trucks.

The most important roads to and from the metropolitan area are identified. Air photos and GIS maps may be of great help in selection of the best locations, but an on-site visit should
always be carried out before the survey to allow for construction work, etc. Then permission to conduct the survey has to be given by the proper authorities.

Usually traffic is only surveyed in one direction, e.g., out of the area. Based on the expected traffic volume and sample size requirements, interview personal is assigned to posts. The sample rate depend on the traffic volume, since a rate of 50-80% may be required to describe the travel pattern on minor roads, whereas 10% may be sufficient on major roads (see, e.g., Equation (5.3) and the following text). The number of interviewers at one post should be limited to 3-7 persons at the time. Depending on the length of survey time, e.g., 6 am to 6 pm, breaks and shifts of interview personal must be planned.

Figure 5.3: Illustration of a systematic process of planning new data collection

If the roadside survey is more or less standard procedure, it is not necessary to conduct a pilot survey. However, experiences often show that costs to pilot surveys are paid back many times. For instance, it is essential that questions are asked, understood, and answered the way they were intended.
It is good practice to appoint an experienced person as head of the interview site to guide the interviewers and take care of unforeseen problems. It may also be required to have police officers present at the site.

Counting of traffic must be done to expand the sample at each site. At best, traffic is counted permanently during a year to capture seasonal variations. Second best, traffic is counted during a week to reflect variations during a week. A common problem with roadside interviews is differences in classification of vehicles interviewed and counted. Automatic vehicle classification may not be that accurate and may not correspond with classification of interviewed vehicles. On the other hand, manual counting of vehicles will not capture weekly and seasonal variations.

Geocoding of origin and destination information to the zonal structure of the model can preferably be done by use of GIS analysis based on reported addresses.

5.8.3 New methods for data collection

New technologies increase the options for data collection (Stopher and Greaves, 2007), e.g.:

- GPS;
- Mobile phones;
- Internet-based surveys;
- Smart Cards;
- RFID-tags.

There are at least three exciting developments occurring in the potentials of GPS surveys.

First, wearable devices are becoming smaller and more easily carried. In current developments, a recording passive GPS has been developed that is the size and weight of the average mobile telephone. This has substantial potential storage capacity of up to 1 Gb of data, although current versions use much smaller memory than this.

Second, there is increasing evidence that the GPS data can be used to provide more than just the time, speed, and position of the user. In her research into the use of GPS, Wolf showed the possibility of deriving trip purpose from a detailed GIS of land use (Wolf, 2000; Wolf et al., 2001). Subsequently, work has been done to collect information on the workplace addresses, school addresses, and frequently visited shops. This permits trip purposes of the majority of trips to be identified from the location visited, with most of the remaining trip ends being identifiable from land-use data. Home, work, shop, and school generally comprise more than 55% of all trip ends, so that less than 45% of trip ends are left to identify from land-use data. Vehicle occupancy by family members can be derived when all members of the household carry wearable devices. In addition, using wearable devices, it has been shown, that mode of travel can be identified very accurately, using speed and route information (Stopher et al., 2005). Thus, with bus routes included in the GIS, together with rail stations, and other terminal points for public transport, bus, train, and ferry trips can be identified readily. Waiting for a public transport vehicle, following a walk to the stop location is also readily identified. Therefore, equipping all members of a household with wearable devices provides
rich information on mode, purpose, time, duration, route, origin and destination locations, and private vehicle occupancy by family members without recourse to interactive PDA’s or subsequent data collection activities.

Third, one of the major problems with GPS devices is signal loss or serious degradation of the signal in various circumstances, including tunnels, urban canyons, heavy tree canopies, and in certain types of vehicles, and the loss of information due to position acquisition delays at the commencement of a trip. Here, research is currently underway to combine the GPS with other positioning methods such as dead-reckoning devices and mobile telephones. For example, it is now well-established that position can be determined to within ±40 m from mobile telephone networks. Using this capability to fill in when the GPS signal is corrupted or absent, while not providing the precision of the GPS positioning, does have the potential to provide significant improvements under signal loss situations. As this research proceeds, it appears likely that GPS records will be more complete than has been the case in the past. A significant advantage of GPS surveys is that they make it readily possible to collect data over many days. For the most part, diary surveys have been limited to one day. In a few cases, two-day diaries have been used, although it is always noted that there is a drop off in reporting on the second day. The other advantages of GPS surveys are obvious. The devices provide very precise geography of the beginning and ending points of travel, and also provide detailed data on the route used. The ability to pinpoint the actual origin and destination of travel may make it possible to abandon the use of the traffic analysis zone as the basis for analysing urban travel, and move, instead, to continuous representation of space in travel demand models. The devices also provide extremely accurate information on the time when the travel took place, and the duration of the travel. With geographic location and time recorded so precisely, it is also possible to obtain very accurate speed data (Bullock et al., 2003). Information can also be obtained on acceleration and deceleration, thus potentially providing the ability to estimate much more precisely the emissions characteristics of a vehicle movement.

One of the detractions from GPS surveys is their expense. On the other hand, the major costs involved in executing the survey would be a recruitment activity, courier delivery and pick up of the devices, and downloading and analysis of the data. Thus, while initial capital costs are high, the actual costs of the balance of the survey are probably quite low.

As mentioned before mobile phone data can supplement GIS data. Many people have a mobile phone nowadays. The mobile network can therefore deliver information about the trips of the telephones and the speed with which they travel. By ‘following’ many mobile phones it is, for instance, possible to create the traffic flows on the road. In the Dutch province of North-Brabant, a pilot study has been done successfully with this method. Figure 5.4 shows average speeds at a specific moment. A low speed indicates a bad flow and possible congestion. These data are updated every minute and can be read from the internet continuously. The data collection is absolute anonymous.

A third new data source comes from the internet. An internet panel is a large group of consumers within one country who on a regular basis respond to different kinds of surveys. This group of people contain as many as 100,000 consumers. Attractive features include that it is very easy to select a specific group (for example, only consumers not older than 45 years
and owning a car), that all kinds of general information is already available (age, lifestyle aspects, etc.), and that results of the surveys can be delivered within a very short time (within one week is possible). Within market research, internet panels are used widely. Until now, they have not been used for the yearly household travel surveys. Most likely, this will change in the near future.

Figure 5.4: Example mobile phone base data collection

A disadvantage in all these sources is the potential bias in who responds to the GPS survey, mobile phone survey, and/or internet-based survey. However, in a recent study, (Hawkins and Stopher, 2004), it was found that the only significant differences between the population and those who took GPS devices were that they were less likely to be people from non-native speaking countries, couple households with older children, secondary school students, low income earners, and large households. However, these are very similar to biases that afflict diary surveys. Current evidence suggests that the biases are no more serious than those already existing in most conventional household travel surveys.

For internet-based surveys, an evident bias is that not all consumers (e.g., old people) have access to the internet. However in some countries access is already above the 60% and for the whole European Union (including Bulgaria and Romania) the average internet access is almost 41%. In the US this is 68%. The internet access per country is shown in Table 5.10 (INSEAD, 2005).
Table 5.10: Internet access in the European Union

<table>
<thead>
<tr>
<th>Country</th>
<th>Share</th>
<th>Country</th>
<th>Share</th>
<th>Country</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>77%</td>
<td>France</td>
<td>37%</td>
<td>Cyprus</td>
<td>22%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>67%</td>
<td>Belgium</td>
<td>36%</td>
<td>Malta</td>
<td>22%</td>
</tr>
<tr>
<td>Denmark</td>
<td>63%</td>
<td>Luxemburg</td>
<td>36%</td>
<td>Portugal</td>
<td>19%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>59%</td>
<td>Estonia</td>
<td>36%</td>
<td>Slovakia</td>
<td>16%</td>
</tr>
<tr>
<td>Finland</td>
<td>51%</td>
<td>Italy</td>
<td>35%</td>
<td>Hungary</td>
<td>16%</td>
</tr>
<tr>
<td>Germany</td>
<td>54%</td>
<td>Spain</td>
<td>33%</td>
<td>Greece</td>
<td>15%</td>
</tr>
<tr>
<td>Austria</td>
<td>42%</td>
<td>Czech Republic</td>
<td>25%</td>
<td>Lithuania</td>
<td>14%</td>
</tr>
<tr>
<td>Slovenia</td>
<td>38%</td>
<td>Poland</td>
<td>23%</td>
<td>Latvia</td>
<td>14%</td>
</tr>
</tbody>
</table>

Smart cards is a new type of payment in public transport. Instead of buying a ticket, one uses his/her smart card which is to be uploaded first. The card has to be used for checking in and checking out at train or bus stations. The trip costs will be automatically calculated and the amount of money available on the card will be reduced by the costs. This system is in a test stadium in Hungary and the Netherlands and brings great opportunities of gathering information about the number of passengers with public transport, which can be used in both building OD matrices and evaluation of public transport assignments.

In freight transport, the application of RFID-tags makes it possible to follow commodities and repair deficits in transport statistics. In the future, this in combination with security scans will allow a tracking and tracing of goods. Whether this will be applicable in freight transport modelling depends on public-private partnerships that can arrange collection schemes and that at the same time guarantee confidentiality for transporters and shippers.

5.9 Derived data and data merging

It is important to distinguish between variables and derived variables, i.e., data collected directly and data derived through more or less complicated procedures. Two examples of derived data are Activity-Based Costing (ABC) in freight modelling and data fusion in demand modelling. These are explained below.

In freight transport, collection of cost data is difficult and often treated as confidential information of transport companies. An alternative for expensive surveys at transport companies is by an estimation method based on ABC. ABC is a costing model that identifies the cost pools, or activity centres, in an organisation and assigns costs to products and services (cost drivers) based on the number of events or transactions involved in the process of providing a product or service. To undertake the transport it is necessary to carry out different activities within a transport chain. Figure 5.5 illustrates an example of a transport chain that contains road transport, loading/unloading and inland shipping.
The process in order to find average transport costs that can be used in modelling is divided into four steps. The tariffs that are important for the decision on the mode choice are different from costs. In most cases, there is a profit mark up on top of the costs. Due to the competitive situation in transport markets, in some cases, the tariffs are lower than the costs and consequently transport firms operate at a loss.

Step 1: During the first step, activities and costs objects are defined. Transport volumes and indirectly transport orders are the basic elements for the cost calculations in the different chains.

Step 2: Based on those transport volumes/orders, activities are defined that are necessary to fulfil the orders.

Step 3: Based on the different activities, costs and cost drivers are defined, e.g., personnel, raw materials, equipment. The cost drivers are defined in for example m³, tonnes, minutes etc. After this, the costs have to be accounted to the different activities.

Step 4: The activity resources will be accounted to the different cost objects.

Schematically the ABC method is pictured in Figure 5.6.

**Figure 5.6: Activity-Based Costing as a method for collecting cost data**

An increasingly important problem in transport modelling is the need to combine information from a variety of different data sources in order to provide the best possible estimate of certain parameters of interest. Problems of this type arise for a variety of reasons:

- No single data source contains sufficient information by itself.
Multiple data sources naturally arise (e.g., through observations at different levels of spatial or temporal aggregation or by means of different survey methods), resulting in a need to reconcile potentially conflicting estimates.

The need to update or transfer an existing set of data and parameter estimates when additional information becomes available.

Although methods have been developed for several specific instances of problems arising in different areas of transport studies (e.g., for OD matrix estimation, synthetic population generation, network performance estimation) there does not yet exist a coherent set of general-purpose methods for dealing with data combination problems. Moreover, due to the lack of appropriate general-purpose techniques, data merging is often in practice undertaken in an ad hoc fashion. For instance, in a recent study of passenger transport in Copenhagen different data sources where merged to estimate OD matrices (Nielsen et al., 2006). It included about 33,000 personal interviews from one-day travel diaries, a postcard survey with about 20,000 trips, and traffic counts. All were combined using statistics and OD matrix procedures.

Polak et al. (2006) describes a general and consistent framework for data fusion based on Bayesian statistics. The framework is designed to enable the use of existing structural knowledge (in the form of existing transport models) and existing measurement knowledge (in the form of characterisations of sampling and non-sampling errors) to inform the data integration task. Notwithstanding many advantages of the procedure, however, the practical implementation of this approach still poses considerable challenges.
6 Freight modelling

Freight models are needed in the process of policy development and monitoring. In order to develop a policy or to monitor it, indicators are needed to measure the effects of policies.

For questions related to the past or current situations, data could be used directly to determine the indicator. For cases where no data are available and future situations, models are needed in order to provide the indicators necessary. These models on their turn rely on existing data on which they can be calibrated.

This logical path is illustrated in the pyramid in Figure 6.1. What can be seen is that for one policy issue a large amount of data, models and related information are needed.

![Figure 6.1: Relation between policy issues and data/models](image)

There are differences between passenger and freight transport modelling. The movements of goods behave in many cases differently than passenger movements. This is because of specific logistical structures where goods are grouped and follow ‘seemingly illogical routes’. In cases where more information can be made available on these logistical structures, the routes become more logic.

In addition, freight transport generally involves longer distances than passenger transport. For this reason, the international aspects are very important even when studying regional or local transport issues. Shifts in the world trade, e.g., the enormous growth of the economy in China, influence the transport movements in European countries and regions. Also within Europe, the national policies of one country influence the transport movements in another country. This is the case for instance if a country raises its toll on the roads so that the freight might follow alternative routes avoiding this country. The impact of these international aspects is much bigger for freight than for passengers. This could also cause models, e.g., at regional scale, to overlook some effects leading to errors in the models that would be minor in the case of passenger modelling.
6.1 Methodological overview

There are numerous reviews of freight transport models around in the transport modelling literature. Most references can be found through the Freight Model Improvement Program website from the US (www.fmip.gov) and the UK (www.dft.gov.uk). Recent freight model literature reviews that include European experiences within an international context can be found in Burgess (2001), Transforum (2006), WSP (2002a), de Jong (2004), and Tavasszy (2006).

This section starts with a brief overview of policy issues. Next, we describe a conceptual framework of the freight transport system and the developments in freight modelling over the last decades. We give an overview of the classical modelling methods, based on an extended stepwise model.

6.1.1 Policy issues

Before we describe the main lines of model development in Europe, we give a short description of the key issues in freight policy that have created the demand for freight demand modelling in the first place.

<table>
<thead>
<tr>
<th>Policy Issues</th>
<th>Modelling Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth of freight: a doubling of freight flows by 2050 worldwide is expected.</td>
<td>Forecasting international freight growth.</td>
</tr>
<tr>
<td>Within Europe, international flows are growing at twice the rate of domestic flows.</td>
<td>Decoupling freight/economy. Sensitivity to cost changes.</td>
</tr>
<tr>
<td>Growing freight shares on the roads: as passenger traffic growth is slowing down and freight is moved by more and smaller trucks, road transport is becoming more dominant</td>
<td>Truck traffic behaviour</td>
</tr>
<tr>
<td>Creation of seamless multimodal networks, new focus on Motorways of the Sea, and inland waterways</td>
<td>Influence of freight intensities on car drivers</td>
</tr>
<tr>
<td>Concerns about international competitiveness of the EU economy, two-way relation between worldwide networks and global trade. “Freight and the economy” discussion: what are costs and (mainly indirect) benefits of freight investments?</td>
<td>Develop suitable worldwide models and continental models. Improve relation between SCGE and network models</td>
</tr>
<tr>
<td>Pricing: Additional charging all modes of transport what they can bear (or, what is fair, given external costs unaccounted for) is becoming reality. EU and member states have different attitudes and strategies towards pricing.</td>
<td>Situational response to cost changes (truck type, road type, time of day)</td>
</tr>
<tr>
<td>Logistic performance: the freight logistics sector is customising its products and is creating complex, flexible networks using advanced logistics concepts such as hybrid supply chains, collaborative networks, e-logistics (both business-to-consumers and business-to-business) and return logistics.</td>
<td>Differentiating between goods with different logistic backgrounds; making detailed statistics available</td>
</tr>
<tr>
<td>Changes in vehicle types: light vehicle growth figures surpass other categories and appear to be more difficult to capture (both in terms of measurement and public policy)</td>
<td>Forecasting (causes and impacts of) choice of vehicle type</td>
</tr>
<tr>
<td>Local environmental damage: new regulations on noise and emissions require more accurate prediction of freight impacts. New technology requires investments. Citizen involvement in freight planning.</td>
<td>Accuracy of forecasts and level of detail (type of traffic, spatial, temporal)</td>
</tr>
<tr>
<td>24-hrs economy: to deal with congestion, firms are spreading production and logistics over day and night</td>
<td>Explaining sprawl of flows to different periods of the day</td>
</tr>
<tr>
<td>Security and safety: traffic needs to be monitored for degree of risk depending on contents or origin of freight</td>
<td>Modelling critical global movements: containers, oil, dangerous goods, food, etc.</td>
</tr>
<tr>
<td>City distribution: as more stern policies are developed for city access and activities, freight requires new delivery concepts</td>
<td>Forecasting of tours at urban level, time-of-day dependent</td>
</tr>
<tr>
<td>Competitive analysis Western and Eastern European truck drivers</td>
<td>Estimating and forecasting nationality of trucks</td>
</tr>
</tbody>
</table>

Table 6.1: Key policy issues and associated modelling needs
Table 6.1 indicates that freight modelling within Europe requires: (i) a growing need for detail (vehicle types, logistics, spatial detail, nationality) and (ii) an extension of dimensions of freight modelling into the broader transport system (geographically as well as functionally, i.e., linking transport and the economy).

Clearly, the existence of the EU Common Transport Policy has fostered the development of all kinds of EU level, international models where one has attempted to satisfy as many of the above requirements for improvement as possible. In particular, the creation of continental models, where domestic and global freight is intertwined, where all modes of transport are relevant, and where borders play a crucial role have been a development typical for Europe. Priorities of the individual countries have often developed in parallel to EU policy and EU-level research, mostly on a more detailed national level. Our focus in the remainder of the chapter will be on the main development lines that have emerged from this national and EU-level research.

6.1.2 Conceptual framework for freight modelling
The conceptual framework of the freight transport system is based on firm/company decisions relevant to transportation demand. The framework for freight transport is illustrated below.

![Conceptual framework of the freight transport system](image)

**Figure 6.2: Conceptual framework of the freight transport system**

In Figure 6.2, five layers are distinguished.

1. The first layer deals with decisions about the location of the production and consumption, type of products and the volume.
2. In the second layer, the relation between production and consumption locations has to be established. To what region will the produced goods be sold (sales) or from what region are the goods bought (sourcing)?
3. In the next layer, decisions have to be made about the use and the location of inventories and about supply chain management.
4. In the fourth layer, it has to be decided what transport modes and what types of vehicles will be used for transporting the goods.
5. Finally, in the last layer, decisions have to be made about the routing in the transport network.
Since the advent of transport modelling, freight modelling has gone through a number of major development stages, building up our knowledge in each of these layers individually, and slowly connecting them to one another.

The first major national attempt in Europe to describe freight transport flows was in the early 70’s (Chisholm and O'Sullivan, 1973). The models focused on the layer of trade, using gravity modelling as a main tool. Freight modelling gained new impetus by the use of input-output (I/O) and Land-Use, Transport-Interaction (LUTI) models, as these explained the interaction between trade, transport and the economy (Williams, 1977). As behavioural modelling took up in the 70’s, the first mode choice models became available for freight as well.

The 80’s were characterised by an increased interest in network modelling and extended network models or hyper-network models, explaining simultaneously trip generation, trade, modal split, and route choice (Friesz and Harker, 1986).

In the 90’s, these models were extended using a multicommodity context (Crainic et al., 1990), improved probabilistic choice models and inventory considerations (Tavasszy, 1996). In the last decade, we have seen an emergence of freight network simulation (see, section 6.4.1). These models have taken up the instrument of microsimulation or network modelling as approaches to describe behaviour of various agents in the system. Their advantage is that they are able to describe actors in detail, while their main challenge is their calibration and validation. Another and closely related new breed of freight models aims to describe agent behaviour by including game theoretic considerations (Thorson, 2005). These models now focus on freight exchange markets and serve both decision makers in the private and the public world.

Table 6.2 summarises these developments from the view of our system framework. The general trend we observe over these four decades are those of 1) increasingly integrative treatment of various decision that firms make, i.e., layers in our conceptual model, and 2) increasing detail of the behavioural content of models, down to the level of simulation in responses of individual firms.

<table>
<thead>
<tr>
<th>Decision problem</th>
<th>Typical modelling challenges</th>
<th>Typical techniques employed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production and consumption</td>
<td>trip generation and facility location, freight/economy linkage, consumption patterns</td>
<td>LUTI (*70s), MRIO (*80s), and SCGE (*90s) models</td>
</tr>
<tr>
<td>Trade</td>
<td>international trade value to volume conversion</td>
<td>gravity models, synthetic OD models (*70s)</td>
</tr>
<tr>
<td>Logistics services</td>
<td>inventory location, supply chain management considerations</td>
<td>logistics choice models (*90s)</td>
</tr>
<tr>
<td>Transportation services</td>
<td>choice of mode, intermodal transport, light goods vehicles</td>
<td>simple trip conversion factors (*70s), discrete choice (*90s)</td>
</tr>
<tr>
<td>Network and routing</td>
<td>routing and congestion, tour planning, city access</td>
<td>network assignment (*80s), simulation (*90s)</td>
</tr>
</tbody>
</table>

Table 6.2: Summary of modelling challenges and techniques
The latest innovative developments in freight system models are the shaded cells in the table and concern the following subjects:

- Improving the representation of freight-economy forward linkages: in freight benefit-cost studies, an important impact to consider is the productivity growth associated with improvements in accessibility. These forward linkages within the economy require models treating the function of transportation in product markets. To this end, spatial economic models are being developed that integrate the first two levels of our framework, trade and production/consumption. The latest addition to this set of models is the spatial computable general equilibrium models (SCGE) models.

- Logistics behaviour: freight logistics models aim to describe explicitly the trade-offs between transport and inventory holding. They build a link between origin-destination (OD) tables for production and consumption locations and OD tables where warehouse locations are included. This is relevant as it determines 1) the spatial patterns for goods flows, changing the usage of infrastructure, 2) the costs of freight movements and 3) the (local and global) economic impact of freight policies.

- Freight trips and networks: In Europe quite some research has been done in the last decade on multimodal network assignment for freight. These models operate at EU and national level and have various degrees of refinement, up to stochastic and multi-user class models. At a more detailed level, the data challenge becomes daunting. Models that describe the choice of vehicle type at a scale of a city or region are virtually non-existing. The main empirical challenges lie in disentangling light goods vehicles from heavy ones, and service from freight-only movements.

A recent phenomenon is the development of simulation models that involve micro simulation/activity based modelling in freight. These are being developed for the urban/metropolitan area, however they are still in an experimental phase.

For freight transport usual practice has been to disregard the middle step (logistics) or to combine it with trade modelling into one distribution stage; this results in a four step approach comparable to passenger transport. There are also other approaches in which several layers from the framework are combined in single steps resulting in:

- One step models (direct demand models);
- Two step models (e.g., combining production/consumption with trade and logistics, and mode choice with assignment);
- Three step modelling approaches (combining trade with logistics and mode choice with assignment).

Below for each of the different layers in the framework a number of techniques/models are described.
6.1.3 Production and consumption
Different methods can be applied to estimate production and consumption, e.g.,

- Growth factor models;
- Trip rate based models;
- Time-series models;
- Input-output models;
- SCGE models.

A simple approach is the application of a growth model. In this approach, base-year statistics on freight trips leaving or entering a zone are scaled up based on regional developments in variables such as employment, population, or GDP. An example of such a model is the NEAC model. This approach requires trip generation models that relate freight trips to aggregates of regional, socio-economic activity.

While base year observations per zone are required in the growth factor models, the demand can be estimated synthetically from aggregates, e.g., of employment, population, or GDP based on trip rates. Such models vary in range from simple trip rate category tables to more advanced discrete choice models.

Time-series models are constructed from historical data sets extended by more or less advanced procedures into future years. This type of models rather describe by extending past trends into the future than explain and assess motives of freight transport.

A different approach involves the application of economic models. Input-output models are built up from input-output tables that describe in monetary units what each sector of the economy delivers to other sections of the economy, and include final demand by consumers, imports, and exports. Trade flows are converted into transport flows (usually in tonnes) using value-to-volume ratios, which are defined for a number of different commodity types. The accuracy of the value-to-volume ratios has a large impact on the model results. Alternatives to using I/O tables are make/use tables. They show for each commodity group which sectors that produce the good and the sectors that receive this good. I/O models are principally non-spatial, i.e., they treat all the interactions within one region. One can add a spatial dimension by using regional shares of employment. Examples of such models are SMILE, SAMGODS, STREAMS, and SCENES.

Another option is the use of non-spatial computable general equilibrium (CGE) and spatial computable general equilibrium (SCGE). These are discussed in Chapter 8.

6.1.4 Distribution of commodity flows
The distribution of commodity flows determines the trade flow relations between production zones and consumption zones. A well-known model to decide the spatial distribution of goods is the gravity model. The gravity model distributes the flows between the model zones using the product of the production and consumption measures for an origin-destination pair, divided by a measure of generalised transport cost or distance. The higher the generalised
transport costs between two regions, the lower the volume of the traded goods between these regions.

The expression (4.1) provides a classical simple double constrained gravity model balanced both at origin and destination. The gravity model should always be single or double constrained to avoid illogical and extreme distributional effects. The use of single or double constrained gravity modelling depends on the formulation of the production and consumption model. In case of directional commodity flows generated in the production zone and consumed at the destination zone, e.g., from a production plant to a city area, a single constrained gravity model balanced by origin with relative zonal attraction rates often has advantages.

Examples of models that apply gravity models are SMILE, EUFRANET and ASTRA. Experiences show that the gravity model is a robust method for modelling the spatial distribution of freight flows.

In traditional transport modelling, a group of models simultaneously calculates production and distribution in the same modelling step. Experiences with this type of models are, however, questionable, and not founded on a sound theoretical framework they risk to produce unexpected results.

If a SCGE model is introduced into freight modelling, then a spatial distribution of flows can be incorporated simultaneously with production based on the theoretical economic framework presented in Chapter 8. This is currently, however, not state-of-practice since only few attempts are been tried in practice, e.g., PINGO (Norwegian freight model).

6.1.5 Logistics services

One of the most obvious manifestations of logistics activities is the growth in freight transport measured in tonne-kilometres. Lengths of haul have been the main past force in creating the increased demand for goods transport rather than increases in the number of tonnes lifted. As this is strongly influenced by changing logistic structures, it becomes important to study effects of logistics. In the White Paper, logistics receives quite some attention in terms of developing “freight integrators”. These new emerging stakeholders in the transport sector are of relevance in developing tailor made solutions for shippers. In this sense a win-win situation could be obtained; i.e., lower cost solutions with lower external cost can be developed, due to efficient combinations; i.e., the longer transport time of intermodal solutions can be compensated by the lower cost and other service characteristics.

The Dutch National Freight Model System was constructed as a joint effort of the Transport Research Centre of the Ministry of Transport and the research organisations TNO and NEI. The name of the model is SMILE (Strategic Model for Integrated Logistic Evaluations). Part of this model is an innovative logistics module.

The main function of the logistic module is to link trade relations to transport relations by considering warehousing services. Here, distribution chains are described by a logistic choice model. Several configuration options for distribution chains are investigated (see Figure 6.3). These are characterised by the number and location of distribution centres. In the choice
model, total logistic costs are calculated that account for handling, inventory, and transport costs for homogeneous product categories denoted as logistical families.

The logistic families are distinguished using the following product and market characteristics:

- Value density (the value of products per m³);
- packaging density (the number of colli per volume unit);
- perishability (the period in which a product is technically or economically usable);
- delivery time (in days);
- shipment size (in tons);
- demand frequency.

Together, these goods and service characteristics determine the physical distribution costs that allow the choice of location and volume of intermediate stocks to be determined. The SMILE model was developed to work with aggregate data.

A similar approach was proposed for the Swedish government (Tetraplan et al., 2002), and specified and implemented as an aggregate-disaggregate-aggregate choice model for Sweden and Norway (RAND et al., 2004). The flows between production zones and consumption zones (P/C flows) are determined in an aggregate fashion, whereas the logistics decisions are treated in disaggregate models. ‘Disaggregate’ means that the unit of observation in the models is the decision-maker (the firm). Although the disaggregate model is theoretically more appealing because it works at the level of an individual firm, a drawback of the detailed approach is that data needs are very demanding.
6.1.6 Mode choice
The choice model splits transport flows by transport mode conditioned on the previous modelling steps. State-of-practice mode choice in freight transport includes:

- Discrete choice models;
- Multi-modal network models;
- Discrete choice model combined with network model.

In practice, discrete choice models are frequently combined with network models. While the choice model splits transport flow by main mode of transport, e.g., truck, rail, sea, and inland waterways, the network model is used to calculate the hinterland transport mode to the final destination or origin. It is a well-established and robust approach, but suffers a theoretical weakness and possible inconsistency by applying two different frameworks of discrete and network modelling.

Discrete choice modelling can be used in many cases, but it usually requires a limited choice set of alternatives. For instance, calculation of transport mode (truck, rail, or ship) used for single transport legs in a transport chain. In Figure 5.5, it could be the question whether to use truck or rail for hinterland transport. In corridor, models where the number of alternative modes and mode combinations is usually rather limited, discrete choice models are often used to estimate mode choice.

Multi-modal network models predict mode and route choice simultaneously. To determine the optimal mode-route path through the network, cost minimisation algorithms are used. The optimal path through the network may involve one or more changes in modes, and therefore multi-modal network approaches can model intermodal movements directly. The costs of each route can contain cost and travel time components by mode, and costs associated with transhipment when multi-mode paths are considered. Examples of multi-modal network models are SAMGODS (STAN), SCENES, and SMILE. Practice shows, however, that it is time consuming and complicated to replicate observed transport patterns in large multi-modal networks.

6.1.7 Network and routing
To determine the routing on the transport network we use assignment models. However, conversion from tonnes to vehicles is needed before the assignment can take place. Usually this is done with simple assumptions about the average weight per loading or carrying unit. The modelling of empty trips should also be done. The easiest way is to increase the number of vehicles by a fixed factor indicating that a certain proportion of vehicles will move around empty. However, as empties tend to travel in the opposite direction as loaded vehicles, this approach is the least accurate. The alternative approach is to take into account the direction of trade and even base the empty trip modelling on the results of the distribution stage.

One type of assignment model is the multi-modal network assignment as discussed above. Another type of assignment model is an assignment that determines the routes in the transport network for a single transport mode. The different techniques used in assignment procedures are treated in detail in Chapter 9.
6.2 Estimation, calibration and validation

Estimation, calibration, and validation of particular concern to freight transport is discussed below as an extension to Chapter 4. According to Chapter 4, modelling parameters can be determined by:

- Estimation methods: if the data availability is sufficient, estimation techniques can be used to estimate the parameter values;
- Calibration methods: calibration is usually carried out when estimation is not possible (for instance because of the shape of the functions) or when the range in which the parameter values lie is known and the exact parameter values have to be fine-tuned in order to fit the model outcomes to the available data;
- When the data availability is not sufficient, parameter values are often based on parameter settings that are mentioned in the literature for similar models. Obviously, this is the least preferred option.

The principles for freight transport are similar to the principles used in passenger transport. However, there is a difference with respect to segmentation. Freight transport is much more diverse than passenger transport, because there are many different commodities, sectors, cargo configurations, cargo packings, etc., which all influence the choice making process. The mode choice for oil will for instance differ from the mode choice of fast moving consumer goods. Besides this there are many other business related factors that influence the mode and route choice. An example of this is the position in the logistic chain. For end products, road transport is often used, because this is a fast transport mode, which can access all locations. In the first parts of the logistic chain, the goods are more often transported by slower modes and in larger shipment sizes. This cheaper way of transport is possible in these parts of the chain, because there is less urgency for reaching the destination.

Data availability in freight transport is often a problem. The data usually do not contain the amount of detail that is required for considering all the aspects described in Section 6.1. In order to be able to calibrate and validate freight models, clustering of different commodities is a generally applied method. Clustering could be done according to, shipment size (or transport volume), domestic/international transport, transport distance classes, geographical area, value density, volume to weight ratios, cargo configuration, cargo packaging etc. The clustering should result in (more or less) homogenous market segments for which data are available. SMILE is an example of a model in which clusters were made for freight that have similar logistic characteristics (logistic families). The amount of clustering is a trade-off between data availability, realistic modelling, and computation time. The more clusters/segments, the better the representation of reality, but the longer the computation and the higher the data requirements.

In case the data availability is poor, the calibration could take place based on aggregates (for example the total modal split) or parameters could be obtained from the literature.

Finally, some general remarks about the different parts of models:
• Trip generation: trip generation models can be calibrated against known zonal commodity production and consumption;
• Trip distribution models require trade data for calibration. OD matrices can be compared as well as trip length distributions;
• Logistic models: the calibration of logistic models requires data about the location and usage of distribution centres (number of tonnes, incoming and outgoing modes, and shipment size, etc.);
• Mode choice: transport statistics can be used for calibrating the mode choice statistics;
• Assignment: the calibration of assignment model requires traffic counts;
• Conversion models: usually the trade models require a conversion from monetary units into volumes and after the mode choice a conversion is required from tonnes into vehicles. This is most often done by fixed conversion rates, which have a large impact on the outcomes. These conversion rates can also be seen as parameters that can be adjusted during the calibration.

6.3 Scenario building

Scenarios are an important part of all modelling studies and apply to freight modelling as well as passenger, economic, and assignment modelling. It describes the future that is to be used for forecasting. The list below summarises items that should be included in European scenarios according to the participants of the TRANS-FORUM project:

• Migration flows within Europe;
• Environmental regulation (e.g., maximum speeds);
• Regional development;
• Tourism (e.g., elderly that migrate to the south of Europe, but return regularly to their home country);
• Local traffic development (to be included in exogenous scenarios);
• Infrastructure development (e.g., include only projects that are stabilised and that will be developed in reality);
• Structural changes in sectors (e.g., the Netherlands becomes a service oriented industry);
• Technology change;
• Institutional development;
• Prosperity.

In general, there is a common agreement about the need for one/two reference scenarios that are standardised and harmonised. This is necessary to avoid each project starting with its own discussion on scenarios to be applied. Moreover, policy-makers can use these scenarios as backgrounds against which to hold their policies for the next few decades. These scenarios should include a limited number of dimensions to avoid too much complexity. The scenarios as developed should be consistent with national scenarios. Possibly the EC can learn from the scenarios as used in the Netherlands and the process of constructing them. In the Netherlands the CPB study “Four Futures of Europe” analysed long-run trends and presented four scenarios for Europe and its countries. These long-run trends and scenarios could also be
adopted at an EC level. In this way the traditional “low-middle-high scenarios” are prevented. The scenarios identified in the Netherlands are set out in the figure below.

- **Regional Communities**: In this scenario, the European Union cannot adequately cope with the eastern enlargement and fails to reform her institutions. As an alternative, a core of rich European countries emerges. More generally, the world is fragmented in a number of trade blocks, and multilateral cooperation is modest. European countries rely on collective arrangements to maintain an equitable distribution of welfare. At the same time, governments are unsuccessful in modernising welfare-state arrangements. A strong lobby of vested interest blocks reforms in various areas. Together with an expanding public sector, this puts severe strain on European economies.

- **Transatlantic market**: Countries primarily focus on national interests in this scenario. Reforms of EU decision-making fail. Instead, the EU redirects her attention to the United States; they agree upon transatlantic economic integration. This yields welfare gains on both sides of the Atlantic, sharpening the distinction between the club of rich countries and the group of developing countries. European countries limit the role of the state and rely more on market exchange. This boosts technology-driven growth and increases inequality. The heritage of a large public sector in European countries is not easily dissolved. New markets – e.g., for education and social insurance – lack transparency and competition. The elderly dominate political markets. These developments make it difficult to dismantle the pay-as-you-go systems in continental Europe.

- **Global economy**: In this scenario, countries find it in their mutual interest to broaden economic integration. Closer cooperation in non-trade areas is not feasible, as governments assign a high value to their national sovereignty in these areas. The problem of climate change intensifies. National institutions are increasingly based on private initiatives and market-based solutions. European governments concentrate on their core tasks, such as the provision of pure public goods and the protection of property rights. They engage less in income redistribution and public insurance, so that income inequality grows.
Strong Europe: Reforming the process of EU decision-making lays the foundation for a successful, strong European Union in this scenario. The enlargement is a success, and integration gains ground – geographically, economically and politically. A strong Europe is important for achieving broad international cooperation – not only in the area of trade, but also in other areas such as climate change. European countries maintain social cohesion through public institutions, accepting the fact that this limits the possibilities of improving economic efficiency. Yet, governments respond to the growing pressure on the public sector by undertaking selective reforms in the labour market, social security, and public production. Combined with early measures to accommodate the effects of aging, this helps to maintain a stable and growing economy.

6.4 Specific freight modelling areas

6.4.1 Logistics networks

The network design and optimisation suite assigned as “The Response model” is developed and maintained by TNO. The Response suite contains a number of sub-models: design and optimisation of logistics networks, selection of location, inventory and routing models, simulation, and cost calculation.

Basically, the design method involves three stages. The first phase comprises of designing the logistics network that has to comply with the requirements for responsiveness and service. In the second phase the costs are estimated using Activity Based Costing (ABC). Finally, phase three sees the design evaluated through simulation. This comprehensive design method is translated in the Response model through three modules, each of which is responsible for one of the three phases in the process.

![Figure 6.4: Three stages of the RESPONSE Suite](image)

The Design module of Response supports the design of a logistics network. It includes many algorithms and techniques that can be applied. For each design problem, the most appropriate algorithm is selected for the particular purpose. The design module of the model focuses mainly on network configuration aspects, such as the design of distribution structures at both national and international level, determining the number of required distribution centres, designing hub and spoke networks, and routing.
The main consideration in determining whether a network design is an attractive option is the costs of the network and the customer service that it offers. The calculation begins by identifying current costs, and these are then used as a reference to assess the quality of the prospective logistics network design.

Once this has been done, the resources that the alternative network options require are identified. This stage draws links between the resources, the activities and the ultimate costs. Next, the costs are ascribed to the various processes on which the network is built. The final step is to ascribe the actual costs for the various sub processes to the various network users. This results ultimately in a division of all the costs in the network to the users. A chief aspect of the method is the calculation of the relationship between the total capacity of the ships, terminals, trucks, etc., and the use of this capacity. This ratio, the level of utilisation, is an important factor in calculating the definitive cost price per pallet.

The third module of the Response model is the simulation module, which contains the possibility to check the designed networks using simulation. Response enables the real situation to be simulated using order data, locations, and logistics features.

Using the combination of RESPONSE™ modules, it is possible to offer solidly founded advice on network design and optimisation to a large variety of clients, and to present the advice in a visually attractive and convincing manner.

Figure 6.5: Network building in RESPONSE
6.4.2 Inland waterways and short distance shipping

Inland waterways transport and short distance sea transport (i.e., not global sea transport but interregional sea transport) account for a large part of the freight measured in volumes in some countries and regions. This section therefore will go in-depth with specific modelling issues for freight transport with this aspect. The focus will be on transport between regions.

Inland waterways plays a role in a relatively small area of the European Community, however where it is available it plays a dominant role. Besides transportation purposes inland waterways (canal, rivers, and lakes) have other purposes such as water management. Modelling systems in the Netherlands for inland waterways also concentrate on this part. Known inland waterway models in the field are the Inland Waterway Model System (in Dutch Binnenvaart Modelsysteem-BVMS).

The Binnenvaart Modelsysteem (BVMS) is a system that predicts the number of shipping movements on the inland waterway network for the respective year. This is based on general freight forecasts produced by other models (such as the Dutch Freight Model SMILE+). It actually transforms a freight matrix into simulated moves of vessels within a year. Within the choice model the vessel type is determined (conventional vessel, tanker, and container) and the size of the ship. Finally, the route on the network is determined. All locks and bridges have been incorporated with actual handling parameters. From the model, the future time on the network and waiting time for locks and bridges can be determined. A number of variants can be evaluated, for example, the height of the water level since it influences the loading of the vessels. For most inland waterway models the demand of transport (e.g., a freight matrix) comes from separate models.
A similar situation as for inland waterways exists in maritime transport, this means that there are few models known that separately estimate the demand of transport. One exception was the port of Rotterdam model (GoederenStromenModel-GSM). It comprised a freight flow forecasting and a port-competition model that included the ports in North Western Europe (Hamburg – Le Havre Range). In the UK, a separate model for maritime flows is developed and maintained by MDS Transmodal. Because of the specific circumstances of the UK; nearly all trade is accommodated by maritime transport. The model is based largely on developments of trade patterns. Again, in the case of the UK, the maritime transport modelling is part of a larger national modelling scheme.

The "GB Freight Model", developed by MDS Transmodal, is based on early work on modelling Anglo-Continental lorry trips and the subsequent work carried out for the STEMM Project, a European Framework Research Project into strategic European multi-modal modelling. The Institute for Transport Studies (Leeds University) has also contributed to the development of the model. The model has since become an open access model of the UK freight industry and is generally available to all interested parties.

The model has in the past been used by the European Commission to identify barriers to intermodality and assess policy instruments, and by the former DTLR to analyse the effects of the Transport White Paper. It has also been used in the validation of the policy scenarios developed by Railtrack and McKinsey within the 2000 Network Management Statement, by the former DTLR ITEA Division in the assessment of the Ten Year Plan and by the SRA for the development of the Freight Strategy. The model is also being used in a number of multi-modal studies, such as the North South Movements in East Midlands and the London Orbital Study.

The model is made up of a database of freight movements, associated simplified networks and cost parameters. It has two modules, an international and a domestic, each of which is given inputs that have the bulk and non-bulk traffic split as a given. The two modules are linked together, so that international traffic is assigned to the domestic network and is distinguished from the purely domestic flows.

Flow data, in the form of origin-destination freight movements, are derived from a number of sources including:

- UK Customs and Excise Trade Statistics (Intra and Extra EU);
- The DfT Continuing Survey of Road Goods Transport;
- The former Railtrack's RTIS sample of rail freight movements;

Other data sources are also used to enhance the quality of the demand data including data sets collected by MDS Transmodal and other parties. Different levels of commodity detail are used in the model, including SITC 2 Digit for the international flows, NST 2 Digit for domestic road, and TOPS codes for domestic rail. These are merged into 20 summary groups that apply to all flows, but in the data set used in the work for the SRA Freight Strategy, eight
product groups were used in the modelling. These are:

- Coal;
- Metals;
- Construction;
- Oil and petroleum;
- International;
- Maritime intermodal;
- Other domestic intermodal;
- Other traffic.

The model analyses flows of goods traffic, using cost models combined with policy levers to predict route and mode choice. The model is network based, generating multi-modal paths for assignment. The interchange network includes all UK Customs sea- and airports, all operational rail-freight sidings and rail-head terminals.

6.4.3 Cargo terminals

On micro level, there exist different simulation models for the flow of intermodal terminal units (ITUs) among and within inland intermodal terminals. The intermodal terminals are interconnected by rail corridors. The terminals are usually represented as serving a user catchment area via a road network. A terminal is modelled as a set of platforms, which are served by equipment (usually a number of gantry cranes and front lifters). The user of the simulation model defines the structure of the terminal and the train and truck arrival scenarios. The train arrivals are defined in a train timetable, while the patterns of truck arrivals for ITU delivery and pick-up can be either statistically modelled or given as a deterministic input. The simulator models can be used to simulate both a single terminal and a rail network, that is, two or more interconnected terminals. During the simulation, various statistics are gathered to assess the performance of the terminal equipment, the ITU residence time, and the terminal throughput. One of the software packages that is used as a development tool is MODSIM III. The Platform project, funded by the European Community is set up along these lines. Usually at large sea terminals, the modelling with micro-simulation takes place along the same lines (for example, ECT in Rotterdam uses quite some modelling in the lay out of their terminals). What distinguishes this approach from macro/meso level is that most cost information is available at the firm and good information of customers is at hand. This usually lacks at macro/meso level.

The INTERMODA (Integrated Solutions for Intermodal Transport between the EU and the CEECs) is a typical approach for a macro/meso approach. Usually for such an approach a macro transport model is used in order to make an estimation of the “potential transport”. The typical freight model provides a useful insight at this level. Sometimes private companies rely on outcomes of transport models. For example, the transport planner of a chemical plant in for example a port has a good idea of the volumes of its own company, but if industrial cooperation is sought for in transport through collaborative solutions it is good to know what the total volume in the port region is. Thus the total production of the chemical industry in the port area is usually retrieved from transport models.
INTERMODA was a research project within the 5th framework programme of the European Commission (DG-TREN). The aim of this project was to develop an intermodal transport network within the Central and Eastern European countries and to link it with the intermodal transport network of the EU by 2015. The development of this intermodal transport network was based in particular on the TINA network and the Trans-European Transport Network (TEN). The main task was to harmonise the different standards (infrastructure, organisation, operation) existing in the EU and the Central and Eastern European countries, in order to contribute to the eastern enlargement of the European Union and to a sustainable transport development.

6.4.4 Taxation and charging
Taxation and charging is a policy measure that has the interest of many government organisations. Also at the EU level, this measure receives attention as appears for example from the White Paper (measure 57). In the TRANS-TOOLS project, a scenario about charging and pricing is included. In more detail, the scenario includes homogenous infrastructure charging for road freight, based on an estimation of social marginal costs. New charges are not added to current charges, but replace them - taking into account the share of social marginal costs already internalised through the fuel excises - and are applied only on motorways for passenger and freight. Charges are applied on a link-by-link basis in the road transport assignment module, which also calculates the revenues on a region level. These revenues will then be returned to the household per country. Besides the route choice, the changed transport costs influence the mode and logistic choices. In summary, taxation and charging, enters different models (modal split models, logistic model, and assignment models) through changes in transport costs on the link level or on the OD level.

6.4.5 Seasonal variation
Seasonal variation is not a core issue in freight modelling, except for agricultural products and summer vacations (less transport) and in countries with large differences in summer and winter climate. Besides seasonal variation, there is some day-to-day variation (less transport on Sundays) and variation within days (less transport) at night. Figure 6.7 (AVV, 2005) shows within day variation on a working day of freight transport in the Netherlands. On the y-axis the number of vehicles per hour is shown (absolute and relative). The purple (dark) bars show the total number of vehicles and the blue (light) bars show the number of trucks. The yellow line indicates the percentage of trucks in the total number of vehicles.

![Figure 6.7: Within variation of freight transport in the Netherlands in 2003](image_url)
7 Passenger demand modelling

7.1 Methodological overview

7.1.1 Introduction

This chapter provides an overview of approaches in passenger demand modelling and their linkages to transport supply modelling. Moreover, the mutual dependencies between the transport systems and the wider spatial environment (including economy, technology, social systems, land-use, ecological systems, etc.) are discussed.

Two main approaches to passenger demand modelling are outlined: trip-based (nested logit) models and activity-based models. Potential improvements are outlined. Since the focus of this report is on the metropolitan/regional level, the state of the art and major trends in land-use/transport modelling are also sketched. Finally, some normative issues in land-use and transport modelling are introduced, requiring approaches of a more complex bi-level optimisation nature.

7.1.2 Metropolitan/regional land-use/transport systems in a wider context

Passenger demand modelling represents one perspective of the metropolitan/regional transport system. The supply side represents the other perspective in terms of infrastructure and flow dependent costs and travel times. This latter perspective is treated in Chapter 9 on assignment modelling. Moreover, the whole transport system is part of a region with localised activities such as residential, employment, service, and recreational activities. The development of the land-use pattern and the location of activities within the overall settlement structure is relying on accessibilities provided by the transport system and is also determining important parts of travel demand in terms of trip generation and trip attraction.

The interacting floor space and transport markets are affected by policies in the decision-making sphere. Some of these policies operate in the middle to long-term time perspective through structural planning and other stable regulations affecting mainly the supply side of infrastructure. Other policies are constituted by more short-term incentives, taxation, and regulations affecting all urban actors in their behaviour, both in the short term and in the longer term. The outcome of the interactions between transport and location at a certain point of time can be measured by a number of indicators covering efficiency, equity, and environmental dimensions of the metropolitan/regional state of affairs. Monitoring such indicators can inform the decision-making system on attainment of political goals like sustainable development and on the need for revised policy measures. A simplified system picture is provided in Figure 7.1. The figure provides some examples of indicators of sustainable development in a metropolitan area. Continuous arrows represent short to middle term processes while dashed arrows represent processes in the middle- to long-term perspective. The long wide (green) continuous arrow represents the utilisation of indicators (in the green oval) for monitoring and evaluation of the sustainability of the urban development.
The metropolitan/regional system depicted in Figure 7.1 is an open system, strongly dependent on external influences in terms of surrounding regions, the national context and continental and global developments in the economical, technological, social, and environmental fields. Of course, our region also contributes to these developments to some extent but most of this wider context can be considered as exogenous for each single region.

7.1.3 Transport demand and supply

The analysis of transport demand and supply has evolved during the last 50 years. To a large extent the development of state of practice in urban and regional transport planning can be explained in terms of the so-called four-step model (see, e.g., Bates, 2000 and McNally, 2000a). The four-step model consists of the following four steps: trip generation, trip distribution, modal split and trip assignment. They are traditionally executed sequentially and in the order just mentioned. However, for attaining the equilibrium illustrated in Figure 4.1 feedbacks between the various steps are required, see Figure 7.2. The figure shows the four-step model with feedbacks in order to reflect equilibrium between travel demand and supply. These feedbacks have in reality been executed to a limited extent and often with heuristic methods that do not ensure convergence. Trip generation has seldom been related to accessibility based on levels of service from the assignment step. Hence, feedback iterations
have mainly concerned linkages between trip assignment and the trip distribution and modal split sub-models.

Other steps of demand modelling are sometimes added into the four-step model, making the iterative scheme even more complex: models of license holding and car ownership (influencing, e.g., trip generation and modal split) and models of time-of-day choice (influencing trip assignment during various time periods, e.g., peak load periods).

By developing so-called combined models, various steps of the four-step model can be integrated and solved simultaneously. The simplest case is the combination of trip assignment and modal split. The solution corresponds to a consistent mode and route choice equilibrium, representing a sound convergence of feedbacks between modal split and trip assignment.

![Figure 7.2: The four-step transport forecasting model with feedbacks](image)

Other combined models have been formulated and solved covering also trip distribution and in rare cases trip generation as well. For various reasons, e.g., lack of commercial software and institutional inertia, these combined models have not developed into state of practice. However, there are examples of large-scale implementations of research-based software, and some versions of commercial software allow “variable demand”, e.g., combined modal split and assignment modelling. For implementing more complex combined models the use of more demanding macro scripts is required.

In the following sections, we will mainly deal with the first three steps of the four-step model, which together make up the demand side: trip generation, trip distribution and modal split. The supply side represented by trip assignment is treated in Chapter 9. The need for equilibration of demand and supply and the handling of feedback iterations must be kept in mind in all chapters on applied transport system modelling (Chapters 6-9).
7.2 The state of practice in passenger demand modelling

7.2.1 Transport demand in context
Before proceeding to the outline of the two modelling approaches, the transport demand analysis should be placed in a wider context. Figure 7.1 shows some of the interactions between the regional development of the economy and land-use on the one hand and the transport market on the other hand (see also Figure 3.3). The modelling of these interdependencies will be discussed in Section 7.4. Analyses of the regional economy and land-use can be conceived as additional steps that are interacting with the transport analysis, see Martínez (2000) and Figure 7.3. Economic modelling is specifically treated in Chapter 8.

![Figure 7.3: Passenger transport demand in a wider analysis and policy context](image)

As mentioned above the analysis of passenger demand needs to be integrated with trip assignment for achieving consistency between demand projections and projections of levels of service (travel time, travel cost, travel comfort, etc.) within the existing transport infrastructure. Policies affecting infrastructure supply and its operation will interact with transport demand management policies. The design of comprehensive policy packages constitutes another level of transport system analysis. In the wider context of Figure 7.3, a clear need for integrated analyses and policy formation can be conceived.

7.2.2 Trip generation and attraction
Practice is mainly represented by less advanced and less integrated implementations of the four-step model. Some typical approaches in modelling trip generation, trip distribution, and modal split will be briefly outlined below, following Bates (2000) and McNally (2000a).

Trip production and generation deals with the question how many trips originate at each zone. Traditionally, we differentiate between trip-based demand models and tour-based demand models. In trip-based modelling, a trip is a one-way movement from the zone where it starts to a zone of destination. Figure 7.4 provides an example where four trips to and from work/supermarket are modelled separately as four independent trips; two home-based work trip (HBW), and two home-based other trips (HBO). We notice, that the first trip is a one-way
trip going from the home zone to work zone, whereas the next trip is the opposite direction from work zone to home zone.

Since trips are modelled independently, the number of trips originating from a zone may be considered as half the number of trips produced in the zone, calculated by generation variables (e.g., population), plus a share of the attracted half of trips, which for each zone is calculated proportionally to its attracted variable (e.g., workplaces and shops). We often refer to such models as trip production models opposite to generation models, which are based on generation inputs only.

**Figure 7.4: Trip versus tour based modelling**

In tour-based modelling, home-based trips (HB) are assumed to be generated in the home zone (generation point) and attracted by the destination zone. An example of the tour-based approach is illustrated in Figure 7.4 where the four separate trips in the trip-based model are treated as two tours instead (home-work-home and home-shop-home). In that way the model takes advantages of the zonal properties, i.e., home zone generation properties (e.g., population and car ownership) and destination zone attraction properties (e.g., shopping places in the city central area) and should be preferred to trip-based modelling.

Traditional approaches for estimating trip generation includes:

- Category analysis for determining relationships;
- Linear regression;
- Discrete choice models.

Linear regression and category analysis determine relationships between number of trip and socio-economic characteristics of the households (e.g., household characteristics, license holding, and car ownership). Car ownership is an important factor since it relates to accessibility benefits associated with car ownership, costs for owning and using cars, travel demand of the household and income. However, there seems to be a strong trend towards
increasing car ownership, even after accounting for explanatory variables (notably income). Although trip production in principle may be related to transport conditions (accessibility), these models seldom include any accessibility or transport system performance variables.

The frequency choice logit model predicts the total number of trips by first calculating the probability that each individual will choose to make a trip. The total volume is then obtained by multiplying the number of individuals of each type by their probabilities of making a trip. In such state-of-practice models, accessibility is incorporated in nested structures via logsums from trip distribution and mode choice models. Disaggregated data are usually used to estimate this type of models while category analysis and linear methods are based on aggregated data.

Trip attraction by zone is traditionally regressed on factors like total employment, retail employment, service employment, etc., and total number of households (see below).

7.2.3 Trip distribution

Trip distribution refers to the problem of modelling the number of trips between any pair of zones $i$ and $j$. This number is generally related to characteristics of the origin (generation) zone $i$, the destination (attraction) zone $j$ and the “cost” of travel between zones $i$ and $j$. Exponential cost functions can be derived from entropy considerations or discrete choice theory.

The predominant early methodology for trip distribution was either simple growth factor methods or gravity type balancing methods. In this latter category, the trip pattern was related to trip productions and/or trip attractions and the generalised travel between zones. The parameter representing cost sensitivity was estimated so that the average generalised travel cost according to the model equals the observed average generalised travel cost, while simultaneously acknowledging the trip production and attraction constraints.

In a forecasting situation the doubly-constrained trip distribution is updated by using new origin and destination constraints and obtaining a new trip matrix through bi-proportionate fitting. If generalised costs are also changed, the cost function is updated before the balancing procedure. In the case of a formulation in terms of destination choice, the destination utilities are updated based on data defining the future scenario.

In the early double-constrained trip distribution models, attraction variables were alone used to predict the number of trips attracted to it. This is generally not correct. The provision of shopping space, for instance, at an inaccessible location will not cause as many trips to be attracted as if that same space was built at an accessible location. Neglecting the accessibility and simply estimating a model of attraction can be shown to bias a model.

The problem can be solved by introduction of accessibility terms in attraction attached to a zone or by applying models only balanced by origin. For instance, home-based tours are often assumed to be single constrained by its origin allowing for the influence from accessibility in distribution of trips. Thus, the total volume of travel is estimated based on generation variables (e.g., population, car ownership) and transport system performance and tours distributed among destinations according to relative attraction and accessibility of the zone.
7.2.4 Modal split
This step determines the distribution of a given number of trips between an origin-destination pair over available modes. The modal split is depending on the generalised costs for alternative modes. Mode-specific constants are introduced to improve the reproduction of modal shares. Empirical functions of generalised cost (“diversion curves”) were often used but have now been replaced by the multinomial logit model or nested logit models.

The ordering of the trip distribution and modal split stages and the averaging of travel costs when going from one stage to the next were subject to debate some decades ago. It is now well established that the order of the steps should be determined in the estimation process and that costs should be averaged as “inclusive values” or “logsums”. The trend has been towards better integration between demand stages and also better integration between demand and assignment (“supply”), e.g., in the form of “combined models”.

7.2.5 Examples of nested logit models
The predominant model type in current passenger demand modelling is the so-called nested logit model category applied to tours (e.g., home-work-home journeys). As explained in Section 4.1.3 the nested logit model is a generalisation of the simplest multinomial logit model in the sense that the total choice set is divided into groups (nests) and the choice probability of an alternative becomes a product of the probability of choosing the relevant nest and the probability of choosing the relevant alternative within the nest, see Figure 7.5 for an example of nested choices of travel mode and destination.

![Figure 7.5: Example of nested model structure](image)

The advantage of the nested logit (NL) model in comparison with the simplest single level multinomial logit (MNL) model is that the assumption of independent and identically distributed (with a Gumbel distribution) random utility terms can be relaxed. The error terms may be correlated within each nest but independent between nests. This idea of nesting can be extended into several levels, thus allowing for still more complex choice structures. The nesting strategy is a way of overcoming some of the strong assumptions of MNL models, reflected in, e.g., the independence of irrelevant alternatives (IIA) property.

It is well known that the multinomial logit model of discrete travel choices can be derived from entropy maximising formulations using individual choice probabilities and observed aggregate or average states of the entire population of choosers. The doubly-constrained gravity model is equivalent to an MNL model of joint origin-destination choice (consistent
with random utility maximisation) up to some aggregation error in the estimated coefficients, see Anas (1983). Nested logit models can also be derived from an entropy maximising perspective by proper choices of objective functions including conditional choice probabilities, see Boyce and Lundqvist (1987), Brice (1989).

Examples on the application of advanced nested logit models in regional passenger demand modelling are provided in Figures 7.6 and 7.7 (from the documentation on the Swedish passenger forecasting system SAMPERS). All three principal steps in demand modelling are addressed: trip frequency (trip generation), mode choice, and destination choice.

Figure 7.6 shows the structure for home-based tours, e.g., trips starting at the home location, travelling to an activity for a certain purpose and returning to the home location. Below the trip/no trip decision in the choice structure one finds in turn mode choice, destination choice and detailed choice of public transport mode (if public transport is chosen as the primary mode). The different choice levels are connected through “logsums”: for instance, in the mode choice part, logsums representing expected utilities from the destination choice are included as explanatory variables.

Figure 7.7 shows the general structure for non-work tours. This can either be of the home-based type reported in Figure 7.6 or the combination of a work trip with either a work-based trip to a non-work activity (i.e., starting from and returning to work) or with a stop on the way to or from the work location (i.e., a secondary destination added to the work trip). In this way some share of trip chaining can be reflected. The model includes links between the various levels in terms of logsums as mentioned above.

Six trip purposes are included: work, business, school, social, recreation, and other. As can be seen in the figures, the following primary modes are distinguished: car as driver, car as passenger, public transport, walking, and biking. At the bottom choice level, public transport is further divided into bus (including underground and light rail) and commuter trains. The transport demand structure of Figures 7.6-7 (from SAMPERS, see Algers and Beser, 2000) is used in the five regional models of the SAMPERS forecasting system. The international passenger demand models in the SAMPERS system is outlined in Section 12.3.1. The link between the national and regional models in terms of access/egress trips to stations and airports is discussed in Section 7.5.
The trip-based or tour-based demand modelling systems mentioned so far provide examples of development of various degrees of integration within the passenger demand structure and various ambitions as regards the handling of trip chaining. The demand models reflect various
choice structures in terms of the hierarchy of generation, distribution and modal choices. In many cases, the choice structure is determined by the estimation process (recommendable). In other cases, the hierarchy of models is imposed by the modeller.

The examples of integrated approaches outlined above can be seen as state-of-practice implementations of the four-step model. These models improve on the main state of practice, which still consists of application of the individual stages of the four-step procedure with manual feedback iterations.

As mentioned earlier in this section nested model structures have sometimes been applied on an aggregate zonal level due to shortage of disaggregate data. Examples of such applications in the context of regional commuter train studies are reported in Lundqvist and Mattsson (1992). Nested models of modal split and destination choice were estimated for three modes and three trip purposes. Such model formulations can also be derived from entropy maximisation principles and integrated in combined models of travel demand and route choice (trip assignment). However, estimation of multinomial logit models on aggregate data should be avoided whenever possible since it introduces aggregation bias in the estimated coefficients, see Ortúzar and Willumsen (2001).

7.3 State-of-the-art activity-based modelling

7.3.1 Development needs in passenger demand modelling
A wider spectrum of transport policy measures has developed in addition to traditional investment planning. Growing traffic congestion and environmental problems in urban regions are increasingly difficult to meet by capacity expansion. Transport demand management includes a broader range of measures such as congestion charging, traffic information, and traffic control measures. In Algers et al. (2005), a number of issues emanating in the new policy context are discussed in relation to passenger demand modelling:

- Temporally detailed traffic supply data;
- Incorporating panel and time series data;
- More realistic and/or flexible decision rules;
- Accounting for population heterogeneity;
- Effects of unreliable travel times;
- Choice of departure time, trip chaining and trip interdependence;
- Accounting for household interactions;
- Responsiveness to changes in institutional constraints;
- Modelling real-time traffic management and information;
- Analysing effects of ICT on travel demand;
- Interactions between the transport system and urban structure.

Many of these issues are directly pointing in the direction of activity-based demand modelling.
7.3.2 Introduction

The activity-based model (the right side picture of Figure 7.8) models the trips in the context of activities compared to the trip- and tour-based approaches discussed in the previous section.

The single most important theoretical work that has motivated researchers and practitioners to study travel demand from the activity participation point of view is the work of Hägerstrand (1970). The time-geography theory postulates that individuals’ activities are limited by a number of personal and social constraints. Hägerstrand distinguished between ‘capability constraints’ (e.g., a need for sleeping and eating), ‘coupling constraints’ (e.g., having the family for dinner requires that the family members are present at the same place and at the same time) and ‘authority constraints’ (e.g., opening hours of post offices and shops). This theory postulates that individuals live in a time-space prism implying that they can only function in different locations at different points in time by experiencing the time and cost of travel and by considering the above listed constraints. The theory assumes therefore that travelling to certain destinations, at certain times of day and by certain travel modes results from the demand for activity participation.

Five important features of the activity-based paradigm are:

- Travel is a derived demand from the activity participation;
- The activity-based approach focuses on sequences of patterns of activities;
- Individuals’ activities are both planned and executed in the household (family) context;
- Activities are spread throughout a 24-hour period in a continuous manner, rather than using the simple categorisation of ‘peak’ and ‘off peak’ events;
- Travel and location choices are limited in time and space, and by personal constraints. This framework is based on Hägerstand’s concept of the space-time prism.

**Figure 7.8: Three modes of travel demand modelling**

The single most important theoretical work that has motivated researchers and practitioners to study travel demand from the activity participation point of view is the work of Hägerstrand (1970). The time-geography theory postulates that individuals’ activities are limited by a number of personal and social constraints. Hägerstrand distinguished between ‘capability constraints’ (e.g., a need for sleeping and eating), ‘coupling constraints’ (e.g., having the family for dinner requires that the family members are present at the same place and at the same time) and ‘authority constraints’ (e.g., opening hours of post offices and shops). This theory postulates that individuals live in a time-space prism implying that they can only function in different locations at different points in time by experiencing the time and cost of travel and by considering the above listed constraints. The theory assumes therefore that travelling to certain destinations, at certain times of day and by certain travel modes results from the demand for activity participation.

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Although founded on theoretical concepts from the 1970s, most work on operational models has taken place during the last decade. The seemingly simple conceptual approach leads to complex modelling issues that have been difficult to handle in computationally efficient and easily transferable standard software. A survey and discussion of activity-based approaches can be found in McNally (2000b).

7.3.3 Discrete choice activity-based models

In discrete choice activity based models, combinations of activity purposes are modelled explicitly in what is called ‘activity pattern models’. An activity pattern can be defined as a sequence of activities planned by an individual. In the Portland model (Bowman et al., 1998; Bowman and Ben-Akiva, 2001), this activity pattern model constitutes the highest level of a hierarchical nested logit system containing five major parts. Lower levels handle in turn time-of-day of home-based tours, mode and destination choice of home-based tours, work-based sub-tours, and intermediary stop alternatives (see Algers et al., 2005).

The activity pattern model of the Portland model handles three primary activities (subsistence, maintenance, discretionary) on tour or at home. If the primary activity is on tour, the activity pattern model also determines the trip chain type for that tour (eight possible tours for work/school tours and four possible tours for maintenance and discretionary tours). The trip chain type is either a simple tour or a chain with intermediate activities on outbound or inbound directions (or both). For work/school tours also a work/school-based sub-tour can be selected. In addition, the possible primary activity/tour type combinations can be combined with any one of six secondary tour types (as defined by number of secondary tours and primary activities). In total, the activity pattern model handles a choice set with 114 alternative activity patterns.

Discrete choice activity based models are relying on the random utility theory that has been in broader use since the mid 1980’s. These models have therefore developed faster than the rule based simulation models. The main theoretical strengths of discrete choice activity based models are the following:

- A large set of activity patterns is handled in the choice set. These patterns are defined in terms of the main activity (e.g., home-work activity), primary tour structure (e.g., home-work-supermarket-home), secondary tour structure (e.g., home-work activity), pattern of intermediate stops, etc. Travel demand is derived from the demand for activity participation;
- Long-term effects can be incorporated in discrete choice models. Prior to the determination of the daily activity patterns, these models may include some lifestyle decisions such as the choice of work location or car ownership;
- Attributes of transport system performance are included in the model structure.

Discrete choice activity-based models lead to a heavier computational burden as compared to standard trip-based models. This may become unpractical in large applications. The use of micro-simulation or sample enumeration techniques simplifies computations and allows modelling of more complex choice structures, but requires large samples. Full population
stochastic simulations have been used in Portland, San Francisco, New York, Columbus and Atlanta.

7.3.4 Rule-based simulation models
Simulation activity-based models construct activity schedules by considering Hägerstrand’s constraints explicitly in continuous time. There are two main groups of these models; activity scheduling models and activity switching models. The difference between the two approaches is that the former group of models constructs the activity schedule from scratch while the switching models alter (or adapt) the pre-defined schedule as a result of proposed changes (e.g., policy changes or infrastructure changes).

The first simulation activity-based models were developed approximately at the same time as the discrete choice theory and the first discrete choice trip based models, i.e., in the end of the 1970’s and the beginning of the 1980’s. Thus, simulation models have a longer history than discrete choice activity based models.

The Albatross model is maybe the best-known and most operational example of rule-based simulation models. It belongs to the group of activity scheduling models and has been developed and applied in the Netherlands (Arentze and Timmermans, 2000 and 2004a). Suggestions for improvements and further development can be found in Arentze and Timmermans (2004b). The brief summary of the structure of Albatross, which is provided here, is based on Algers et al. (2005).

For each (adult) individual in the household the model determines how the daily activities are generated, sequentially ordered and combined into chains, while observing various temporal, spatial, and institutional constraints. The scheduling process is modelled as a heuristic search process guided by decision rules represented in a decision table derived from activity diary data. The scheduling process starts with exogenously specified fixed activities, constituting the skeleton of the schedule. The location, start time, and duration for these mandatory activities are assumed exogenously given. Travel mode is decided for each primary work activity. Flexible activities are then added to the skeleton in available time slots. Trip chains are formed and travel mode is chosen. If the chain contains a work activity the travel mode is restricted to the mode of the work trip. Finally, location and travel time are decided for flexible out-of-home activities.

The decision tables governing the scheduling process define actions for each combination of conditions describing the choice context. These decision rules are derived from empirical data and attempts are made to reformulate the conditions in order to increase the homogeneity in observed actions. Actions can be assigned deterministically (action corresponding to highest observed frequency) or probabilistically (according to observed frequencies). Instead of including variables such as distance among the conditions (in terms of distance classes), the choice of action can be modelled as a function of such variables. Such parametric choice models (e.g., a multinomial logit model) are estimated on the observed data with the continuous variable (e.g., distance) as an explanatory variable. This flexible form of decision table is a recent generalisation and has been called parametric action decision table (PADT).
Important theoretical strengths of rule based simulation models include:

- Demand for travel is derived from the demand for activity participation in a manner that is intended to be close to actual decision-making;
- Time, location, and budget constraints are incorporated explicitly in the model structure;
- The time component is modelled continuously;
- Many simulation models are household-based.

The strengths of one model type are the weaknesses of the other. Discrete choice activity-based models rely on widely practised techniques for the formulation, estimation, validation, and forecasting with random utility based models. The Portland model has been transferred to other US cities and extensions have included ways of capturing intra-household effects. The Albatross model is available as software and is well documented. It has been successfully implemented in the Netherlands. Given the exogenously specified fixed activities, the model seems to predict the activity patterns reasonably well. The transferability has not been investigated. The computational burden is high for both types of activity-based models.

### 7.4 State of the art in land-use/transport modelling

#### 7.4.1 Descriptive approaches in land-use/transport modelling

Wegener (1994, 1998, 2004), Wegener and Fürst (1999) and Hunt et al. (2005) have reviewed the state of the art in land-use/transport modelling. Twenty models developed in various parts of the world are compared (ten from North America, six from Europe, two from South America and one each from Australia and Japan). A few of these have acquired wider use in several cities, notably the ITLUP, TRANUS, and the MEPLAN systems, which are available as commercial software. The DELTA land-use/economic model has been applied in an increasing number of cities (in conjunction with different transport models) and many of the other models have also been transferred from their origin cities, at least in research contexts. The models are compared in terms of comprehensiveness, model structure, theoretical foundations, modelling techniques, dynamics, data requirements, calibration and validation, operationality, and applicability.

The TRANUS and MEPLAN models together with Wegener’s IRPUD model were applied to seven cities (TRANUS: 2, MEPLAN: 4 and IRPUD: 1) in the PROPOLIS project of the 5th Framework Programme of the EU. These models can be seen as representative examples of the state of the art in equilibrium or quasi-dynamic integrated land-use/transport modelling. Within PROPOLIS these models were embedded in policy, impact evaluation, and appraisal schemes aiming for urban sustainability. All three land-use/transport models are recursive, i.e., changes in land-use during a period are conditioned by the transport equilibrium resulting from land-use/transport interactions of the previous period.

Land-use/transport modelling based on spatial computable general equilibrium (SCGE) approaches have been developed both for regions with simplified geography and for general
urban zonal topologies. This type of models applied to the interregional scale is further discussed in Chapter 8. Anas and Xu (1999) developed a model for a circular symmetric geography, which is currently extended to a general system of zones and integrated with a stochastic transport equilibrium model (RELU-TRAN). Urban SCGE models can be seen as an emerging state of the art in equilibrium land-use/transport modelling. An even tighter link between the transport equilibrium and land-use changes are reflected in some extended “combined models”, where not only travel demand is integrated with the route choice equilibrium (traffic assignment) but also location of activities (see, e.g., Kim, 1989). However, neither urban SCGE models nor extended combined models have developed into state of practice, which is rather represented by, e.g., ITLUP, TRANUS, or MEPLAN applications.

The need for further geographical disaggregation and dynamics has been mentioned in review articles as two main directions for future land-use transport modelling. Figure 7.9 (Wegener and Fürst, 1999, adapted from Miller et al., 1998) outlines one frequently published “mapping” of development trends in land-use and transport modelling.

<table>
<thead>
<tr>
<th>Transport model</th>
<th>Land-use model</th>
<th>I1: No public transport no modal split</th>
<th>I2: Public transport no logit 24 h</th>
<th>I3: Public transport logit peak hour</th>
<th>I4: Multi-modal activity-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1: None</td>
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<tr>
<td>I2: Activity and judgement</td>
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<tr>
<td>I3: No market-based land allocation</td>
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<td>I4: Logit allocation with price signals</td>
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<tr>
<td>I5: Market-based land-use model</td>
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<tr>
<td>I6: Activity-based land-use model</td>
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</tbody>
</table>

Figure 7.9: Trends in land-use/transport modelling

The trend towards more integrated models of transport demand and supply is indicated in the first and second rows, while a similar trend in the development of land-use models is indicated in row 3-6. As can be seen, the figure postulates a development into micro-simulation and
activity-based approaches both in land-use and transport. Similar assertions are made by, e.g., Timmermans (2003) and Hunt et al. (2005). Some candidate models mentioned in these reviews are ILUTE (Canada), ILUMASS (Germany), TLUMIP (USA), and RAMBLAS (the Netherlands). However, most of these candidates are still subject to research and/or have not been transferred to other regions than their original spatial context.

After a summary of the state of practice in transport modelling in the US and the UK, Boyce (2007) commented that many practitioner software systems (like CUBE, EMME/2, PTV Vision, QRS II, SATURN, or TransCAD) are capable of implementing integrated models of demand and supply. However, this requires that the forecaster has acquired the appropriate knowledge of the models and the algorithms. An alternative to offering “tool kits” for building models might be to design a software system that directly solves an integrated model including providing a number of options to the user. This suggests an emphasis on standards for travel forecasting software as well as for travel forecasting practice rather than upgrading practice model by model. Boyce concludes by observing that an attitude that travel forecasting ought to be simple has contributed to the state of practice being substantially inferior to the state of the art.

Many arguments for activity-based approaches refer to the importance of household interactions (activity scheduling, car ownership) and institutional constraints (opening hours). However, some trends in current societies are pointing in other directions. The household size is decreasing leading to an increasing share of single person households. Working hours are diminishing in the long-term (and redistributed between sectors). Working hours and opening hours are becoming more flexible and telecommuting and teleshopping contribute to higher flexibility. Car ownership is increasingly seen as individual-based rather than household-based. Such development trends tend to make mobility patterns less constrained.

7.4.2 Normative approaches in land-use/transport modelling
Although the equilibrium concept is important in transport modelling, many such problems can formally be stated and solved as equivalent optimisation formulations. This is, for instance, the foundation for algorithms solving the deterministic user equilibrium route choice problem (Chapter 9). As noted earlier, many supply-demand equilibriums can be formulated as “combined models”, which are also stated and solved as equivalent optimisation formulations.

More truly normative problem formulations can easily be found in the land-use/transport modelling context. Examples are, for instance, network design, estimation of origin-destination matrices, and design of toll systems for congestion charging. All these problems are known as bi-level problems, which are inherently difficult to solve. In network design, the upper level objective may be maximisation of welfare or minimisation of total costs, while the lower level objective is related to the equivalent optimisation formulation of supply-demand equilibrium on the transport market. The design capacities constitute the variables to be decided. In OD estimation, the upper level objective may indicate the absolute “distance” between a previous OD matrix and the estimated matrix and/or the absolute “distance” between observed flows and estimated flows, while the lower objective again represents the transport market equilibrium. The OD matrix entries constitute the variables to be decided.
Finally, in designing toll systems, the location of toll stations and the choice of toll levels should be decided in order to minimise, e.g., total travel cost (upper level), while retaining supply-demand equilibrium on the transport market (lower level).

Similar normative approaches may be applied in land-use/transport modelling. For instance land release and transport network investments can be decided in order to maximise urban welfare (upper level) while using equivalent optimisation formulations for ensuring equilibrium on urban markets (lower level), compare Figure 7.1.

### 7.5 Specific passenger modelling areas

#### 7.5.1 Changes in trip patterns
Changes in trip patterns are computed as a result of scenario assumptions and transport policies and are core results of passenger demand modelling. The basic hypothesis underlying the models is that the estimated behavioural parameters are stable over time. This assumption may be changed if other information is available on future valuations. For example, the value of time may be related to future income. However, introducing such changes may be done in many ways and may require both experience and theoretical considerations.

The trip patterns are strongly related to the travel times, travel costs, and other travel performance variables produced in the assignment step. The parameters of the generalised cost (e.g., the value of time) in the assignment step should be compatible with parameters obtained in the estimation of the passenger demand models. By introducing tolls or changing public transit fares, the generalised cost components are changed, both directly and indirectly via changed route choices and congestion. The new generalised cost components affect passenger demand trip patterns: travel frequency, destination choice and mode choice. Additional iterations may be required for achieving consistency between travel demand and trip assignments.

#### 7.5.2 The choice of access/egress modes
National and regional passenger demand modelling is truly multi-modal. The re-balancing of modes is a key interest in metropolitan contexts, e.g., for reducing congestion, for improving the environment, and for distributional reasons. The high degree of interactions between mode choice (as part of travel demand) and the assignment step has been emphasised in the previous section.

Most trips are inter-modal in the sense that walking, biking, or feeder bus is used to access the public transport means. Walking is necessary at the origin and destination of car trips. Park-and-ride is increasingly used to access high frequency public transport systems from sparsely populated areas.

The quality and choice of access/egress modes to railway stations and airports affect the regional travel patterns and the competition between rail and air on the one hand and between airports and railway stations on the other hand. For example, better access to a larger or cheaper airport by high-speed rail or a new motorway may lead to shifts in the choice of
airports and in the use of feeder modes. In some regional projects – e.g., the Öresund Bridge and the new high-speed railway between Amsterdam and Rotterdam – traffic to airports play a significant role.

The use of feeder modes for long-distance rail and air trips is modelled in the regional models of the Swedish SAMPERS system based on long-distance travel demand according to the national model. The following feeder modes were considered: car parked at station/airport, kiss & ride, taxi and hired car, bus, train, and walk/bicycle. Different models were estimated for private trips and business trips and, if possible, for the origin and destination parts of the tour.

7.5.3 Taxation and charging
Pricing, taxation, and charging policies are introduced in relevant models, e.g., vehicle taxation in the car ownership model, fuel taxes, income tax deductions and road tolls in the auto assignment model and fare reforms in the transit assignment model. Taxes or tolls for financing road systems have been studied in land-use/transport models of the spatial computable general equilibrium type, see Anas and Xu (1999).

In most of these cases, cost changes are directly introduced in the assignment step, leading to a new equilibrium of generalised cost, route choices, and congestion. The results from the assignment step are fed into the passenger demand models and iterations may be required in order to achieve a consistent transport market equilibrium. If it is possible to use a “combined” model of demand and supply, the solution of this model would directly provide such a consistent equilibrium solution.

7.5.4 Seasonal variation
Seasonal variation may be a core issue in passenger models in some nations and regions with a high share of tourism, and it may be studied at all levels: European, national and regional. This can be relevant for certain corridors or border crossings, but tourism can also be part of international and national passenger demand modelling. Dummies may be introduced to take into account seasonal variation in the propensity to use bicycles.

In regional contexts, the variation between weekdays and weekends tend to be more important. In many metropolitan regions, weekend traffic leads to serious congestion, which may require specific travel management measures.

7.6 Other issues

7.6.1 Background forecasts
Information on future background variables are often stated in terms of future scenarios for population, employment, income, fuel prices, transit fares and other exogenous input data required by the passenger demand and travel assignment models. In addition to such exogenous future scenarios, information is needed on how alternative policies affect the input data of the system.
Some of the required background data can in turn be obtained from (national or) regional economic models (see Chapter 8), land-use/transport models (see Section 7.1.6) or car ownership models.

The scenario data are subject to uncertainty, often to an unknown degree in any a priori evaluation of a certain policy. In the after-situation, the error in the background forecast is known and its impact on the model projection can be computed in order to separate the “scenario error” from the true “model error”. This model error can be used for before-and-after external validation of the passenger modelling system.

### 7.6.2 Uncertainties

In Section 4.5, many sources of uncertainty are mentioned that are also relevant for passenger demand modelling. In addition to uncertainty of background forecasts, these sources refer to input data (including finite sample size), estimation methods, calibration methods or solution methods. Few of these uncertainties have been subject to systematic studies. Estimation methods produce parameters with some degree of significance. The impact of the uncertainty related to the use of a certain sample can be studied by bootstrapping methodology, see Beser Hugosson (2003).

For evaluating the size of the overall model error (or model uncertainty) discussed above, external validation of the model on good before-and-after data should preferably be undertaken. Good candidates for policy cases are, e.g., the fixed link over Öresund (long projection period) or Stockholm trial on congestion charging (short projection period). It is however a frustrating experience that it is typically very difficult to raise support for external ex-post validation of a forecasting approach that has been used in the context of an important policy decision.
8 Economic modelling

Economic models are important to highlight consequences of transport policies that are not covered by transport models and they are important to calculate changes in demand for transport that can be used as inputs to transport models. Transport demand is derived from economic activities. The economic input can be at several levels. In Figure 8.1 below transport demand is considered as the first two stages of the four-stage model, whereas other approaches see the economic input to transport demand happening only at the first stage or sometime as an exogenous input to the first stage. Economic modelling is thus described on its own. Most transport models have an economic component. In addition, also “feedback processes”, i.e., the effect of improved accessibility (through transport policy) on the economy need attention. Spatial general equilibrium models are relatively new elements in transport models, while prior models build on input-output tables.

Several studies have shown that the magnitude of indirect effects and effects related to spending revenues from, e.g., road pricing, are comparable with the direct effects (summarised in, e.g., Bannister and Berechman, 2000). Doll and Schaffer (2007) show that the employment increases with about 39,000 jobs as a consequence of spending revenues from the German heavy vehicle fees (HVF). The economic analysis can further show the distribution of effects across regions (if a spatial model is used) and across industries. The distribution of employment effects in the German case as consequence of spending revenues from heavy vehicle fees is shown in Table 8.1 (Doll and Schaffer, 2007).

<table>
<thead>
<tr>
<th>Industry</th>
<th>Employment effects</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New jobs with productivity growth of 10 %</td>
<td>New jobs without growth of productivity</td>
<td></td>
</tr>
<tr>
<td>Construction services</td>
<td>28,200</td>
<td>28,500</td>
<td></td>
</tr>
<tr>
<td>Business-related services</td>
<td>2,500</td>
<td>2,700</td>
<td></td>
</tr>
<tr>
<td>Ceramics and building materials</td>
<td>2,300</td>
<td>2,500</td>
<td></td>
</tr>
<tr>
<td>Complementary transport services</td>
<td>1,200</td>
<td>1,300</td>
<td></td>
</tr>
<tr>
<td>Wholesale</td>
<td>1,000</td>
<td>1,100</td>
<td></td>
</tr>
<tr>
<td>Financing</td>
<td>700</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Wood and wood products</td>
<td>550</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Supporting construction services</td>
<td>500</td>
<td>550</td>
<td></td>
</tr>
<tr>
<td>Electronics</td>
<td>400</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>Road transport</td>
<td>400</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td><strong>Whole economy</strong></td>
<td><strong>36,200</strong></td>
<td><strong>39,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 8.1: Distribution of employment effects for Germany, 2003

The economic models can as in the German case be used to emphasise additional benefits (or costs) arising complementary to the direct transport effects. Some of these complementary (or second-order) effects can be politically very important to illustrate. Moreover, the models are...
used to illustrate differences in impacts on different agents in the model; like the example for different industries in Table 8.1.

The very different uses of economic models emphasise the different requirements to basic data input. Economic models address different questions and the data needed for models addressing the questions vary. Three typical economic modelling approaches can be distinguished.

1. Economic models linked to passenger transport,
2. Economic models linked to freight transport, and
3. Economic models without linkage to specific transport models.

The main purpose of the economic models of type 1 and 2 is as input to the prediction of demand for transport, which can be used as input to transport models, based on economic activities. TRANS-TOOLS includes such linkages from the CGEurope economic model to the passenger model (VACLAV) and the freight model (NEAC). A national model structure with some of the same linkages is found in the Swedish SAMGODS model (SIKA, 2001), where a macro-economic input-output model is linked to freight distribution and assignment.

The link of economic models with transport models is basically a matter of including the underlying driving forces for transport on a long-term basis. The economic model can be run as a separate module of the traffic models as in the traditional four-stage models shown in Figure 8.1. The four-stage model/economic model can have feedback loops, but in many applications, this is not included in the models.

![Figure 8.1: Substitution of demand stages in four-stage model with economic model](Image)

There are, however, models where the economic models are more integrated in the model structure. Such examples are found in TRANS-TOOLS (see Figure 8.2) and in the ASTRA model (see Figure 8.3). The integration of these models is done through iterations between the different sub-models.
The specific integration between economic models and transport models can, as these examples show, be carried out in different ways. Sometimes with close integration and many feedback loops, sometimes as simple sequential models. The substitution of sub-models in the four-stage model sometimes encompasses both generation and distribution, and sometimes the distribution is carried out in the traffic model as illustrated in the TRANS-TOOLS model. However, an initial distribution of production and consumption on regions is carried out in the economic sub-models of both TRANS-TOOLS and ASTRA, but the conversion to origin-destination matrices is contained within the traffic models.

The third type of models listed above – the independent economic models – may address specific issues such as the interaction between transport as an economic sector and other economic sectors or markets (e.g., the labour or housing market), or how taxes in transport influence demand for goods, leisure transport, etc. There are many models of the third type.
with focus on a large number of different issues. Each model has a specific data requirement. Parry (2002) uses a generic model, not specific for any region to analyse the efficiency of different short run policy measures aimed at reducing congestion. Parry’s model does not require a particular set of data. In the other end, but focussing on the same question as Parry (2002), is Liu and MacDonald (1998), who focuses on a specific lane on a highway in California to investigate the efficiency of different toll regimes.

The input-output model used by Doll and Schaffer (2007) to analyse the economic impact of the German heavy vehicle fees is also very data demanding. Not only is a detailed input-output table of the German economy required, but they also use data on the behaviour of hauliers to prices of transport to describe the transport cost changes in different economic sectors. This third type of models is in many cases not related to traffic models, but can in some situations act as the economic sub-model in the above mentioned model systems (e.g., CGEurope in TRANS-TOOLS).

Data availability is generally very good in the EU15 both with respect to the richness of detail and the long time periods of economic data. There has in many new member states not been a comparable tradition of data collection especially on the economic data. This means that models based on time series (see in the subsequent sections) are difficult to develop. However, many newer models do not even require time series data. This is particularly true for the computable general equilibrium models (CGE), which are described in some detail below. There are other types of models that are also based on cross-section data like the CGE models. A common base-year data set is constructed with the level of detail required to develop the model. One example is the construction of social accounting matrices (SAM) used in for example CGE models. The SAM can in principle be designed for any year. Elasticities are a very crucial element in the creation of modern economic models. Emphasis should instead be put on finding very good elasticities for substitution between different components. This conclusion does not depend on a particular mode of transport or area within transport (freight or passenger).

One particular problem arising from the lack of time series of adequate length is in relation to forecast models. Models predicting future patterns in transport demand. Due to short time series, it is not possible to estimate time series models significantly. One other possibility is to use a single year and cross-section data and perhaps include a time dimension. Without the time/dynamic dimension, it is difficult to validate the approach chosen to include the dynamic year-to-year changes.

8.1 Methodological overview

Economic models in transport modelling are covering a range of aspects. Different model approaches have been applied, and economic models have addressed many types of questions. Economic models serve both as the generator of transport or traffic demand in transport models and have their independent purpose in addressing very specific issues. This latter type of models has often served to analyse limited and very specific questions. An example is the impact on commuting when tax reductions from commuting are introduced (e.g., Anas, 1999; Pilegaard, 2003; Potter et al., 2006, for an overview of methods), they are used to analyse various second best issues related to different types of tax instruments (e.g., Verhoef, 1996,
Even though the specific economic models provide many interesting insights into the working of many of the suggested types of economic regulation they are not really the type of models that are in focus in the present project. The focus in this section is on models of the “real world” in which identifiable regions, sectors, types of households, etc., are analysed. The models are thus models of, e.g., the national economy, the economy of regions and trade between regions, household decisions with respect to commodity demand, and transport demand. However, we will include the theoretical studies when they can give additional insights in a particular issue.

Economic models are often linked to other models either as a direct integrated part of a transport model or in a separate outside model linked in a systems approach. Economic models play an important role in relation to the generation of traffic. Freight transport demand is derived from the need to move goods between seller and buyer in different geographic locations. The trade of goods is in most transport model (systems) calculated using a specific economic model or economic sub-module. The various possibilities for applying these models are described further below.

Passenger traffic demand is also derived from linkages to economic activities; e.g., commuting. However, many personal trips are not directly linked to an economic activity; leisure trips are not directly motivated by a pure economic benefit. The leisure trips are derived from activities giving personal utility, which is an economic activity. Due to this, economic models have not played the same crucial role in relation to passenger models. The economic variables included in most passenger transport models are GDP growth, location patterns and prices. These variables may come from economic models (e.g., macro-economic national models), but often there is no specific economic model included.

Before describing the specifics of the various models, it is necessary to get an insight in the typical theoretical approaches for economic modelling.

8.1.1 Gross model list
Methods for deciding production and consumption are discussed in a number of international reviews, among others RAND Europe (2001), Pendyla and Shankar (2000), and Tavasszy et al. (2000). An alternative review is Janssen and van den Bergh (2000) that describes economic flow models based on the energy sector. Here gross lists of various model types for estimation of production/attraction or more generally, economic flows between regions and sections are set up. In addition to the gross list, the dynamic macro-economic models are also included. A detailed description is given in Section 8.1.2 on input-output models and the general equilibrium models. The following model types will be discussed below:

- Input-output models;
General equilibrium models or CGE models;
Dynamic macro-economic models;
Cost minimisation models;
System dynamics models;
Time series models;
Zone-based trip rate models.

The focus in most of these models is on freight flows, but the models can also be used in relation to passenger transport with small adjustments in the theoretical basis.

8.1.1.1 Input-output models

Input-output models represent flows of money and goods between the various producers and consumers in the economy. The models are based on Leontief substitution technology, which implies an assumption that companies produce goods in fixed proportions between the factor input (labour and capital) and between other intermediate inputs. This means that even if some inputs become relatively more expensive compared to others the companies will use the same mixture of input as in the base situation. This is a restrictive assumption, as companies as a rule will change the collection of input if the relative prices change. It is in this context an issue of substitution effects in the production.

As regards data, the models are typically based on input-output tables or a social accounting matrix (SAM), representing the economy as a set of balanced accounts. Contrary to the input-output tables a SAM includes both an account of production and input, and an account of income and final demand, which is related as “induced effects”. The advantage of this model is the description of how the demand (including exports) leads to production in several phases through the companies’ demand of input (including import).

An input-output model is based on input-output tables. They specify the amount of output from a given industry that is used in another industry for production, and for final consumption in private households or by the government. An input-output table similarly tells how the inputs to one industry are composed of outputs from other industries. The general content of an input-output table is shown in Table 8.2.

<table>
<thead>
<tr>
<th>Intermediate flows</th>
<th>Final demand</th>
<th>Total output</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_0 )</td>
<td>( f_0 )</td>
<td>( x_0 )</td>
</tr>
<tr>
<td>Value added</td>
<td></td>
<td>Aggregated value added ( v_0'e )</td>
</tr>
<tr>
<td>( v_0' )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total input</td>
<td>Aggregated final demand ( e'f_0 )</td>
<td></td>
</tr>
<tr>
<td>( x_0' )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8.2: General content of an input-output table

\( X_0 \) is the \( n \times n \) matrix\(^3\) of intermediate flows with a typical element \( x_{ij}^0 \) that denotes the value of deliveries from industry \( i \) to industry \( j \). \( f_0 \) denotes the vector of final demand in households,

---
\(^3\) \( n \) denotes the number of industries in the model.
To use the I/O tables as a model we need to calculate both the input coefficients as $A_0 = X_0 \hat{s}_0^{-1}$ and $B_0 = \hat{s}_0^{-1}X_0$. Using this we can write the output from the industries as

$$x_0 = A_0 x_0 + f_0 \leftrightarrow x_0 = (I - A_0)^{-1}f_0$$

(8.1)

for the demand driven I/O model and

$$x'_0 = v_0 (I - B_0)^{-1}$$

(8.2)

for the supply driven model. The models can be used in two ways either to calculate changes in output due to demand changes using (8.1) and assuming that the input coefficients are fixed, or a supply driven change assuming the output coefficients are fixed:

$$x_1 = (I - A_0)^{-1}f_1$$

(8.3)

$$x_2 = v_2 (I - B_0)^{-1}$$

(8.4)

Doll and Schaffer (2007) use an input-output model to analyse the supply-driven effects on prices and the demand driven employment effects caused by spending the revenues from heavy vehicle fees in Germany. The use of input-output models in relation to transport models has some weaknesses especially because it is not possible to calculate output effects as shown by Oosterhaven (1998) and Dietzenbacher (1997) and because coefficients are fixed. This implies that the models are not capable of establishing a new equilibrium between demand and supply and cannot incorporate behavioural changes in, e.g., demand (due to the Leontief fixed coefficient structure).

Input-output models have been used to form the basis of the economic sub-modules of several European freight transport models such as STREAMS, SCENES and ASTRA. These three models are macro-economic models. They describe in monetary units what each sector of the economy delivers to other sectors of the economy, and include final demand by consumers, imports and exports. The monetary flows predicted by input-output models need a spatial dimension in order to be converted into OD matrices of trade flows. Trade flows are converted into transport flows (usually in tonnes) using value-to-volume ratios that are defined for a number of different commodity types.

**8.1.1.2 Computable general equilibrium models (CGE)**

CGE models are typically comparative static equilibrium models of interregional trade based in microeconomics using utility and production functions with substitution between inputs. Spatial CGE models (SCGE) and non-spatial (CGE) have many similar characteristics. The main strengths of the CGE models lie in the comparison of outcomes in different
equilibriums, and that the models are strongly based in microeconomic theory, which gives the advantage that results are readily interpretable based on a strong theoretical literature. The CGE models are ‘comprehensive’ and include relations between sectors, supply and demand, households, economic regulations, etc., in potentially very complex non-linear ways. The models can thus be used to analyse problems, where many different things are working at the same time and when, e.g., behaviour has to be close to reality, it further takes proper account of both first and especially the complex second-order effects.

Van den Bergh (1997) describes a very simplified and stylised spatial general equilibrium model to demonstrate the suitability of this model tool to analyse different types of policy instruments (illustrated in Figure 8.4). Van den Bergh’s model, however, is too simplified to be of real practical use, but it can easily be extended towards real policy analysis. One of the earliest spatial CGE models in Europe is described in Bröcker (1998b) who demonstrates that a SCGE model can be set-up using data that are available in almost all countries. The model is an international model, but the same methodology applies to national models as well if data on this level of detail are available. Bröcker (1998a) applies this model to show how an expansion of EU will affect Europe’s economic geography. Bröcker (2000) describes how the same model can be applied to the assessment of spatial economic effects of transport.

The Bröcker methodology has also been applied in the Norwegian PINGO model (Ivanova et al., 2003). PINGO is a national model describing interregional trade; the model is used for the analysis of the national transport plans, where investments are in focus. Spatial CGE models have been used for some time. Partridge and Rickman (1998) give a review of primarily early American and Australian based models. Despite this very early development still only very few practical applications have been published.

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Figure 8.4: General structure of a (regional) CGE model
A stylised and very general presentation of a CGE model is shown in Figure 8.4. The figure illustrates the primary components of a CGE model and the important links between them. The supply (or the production of goods) creates demand for value-added factors (labour and capital), and goods and services as intermediate inputs. These inputs can be met locally or through imports from abroad or from other regions, when the model is spatial. In the non-spatial versions inputs can only be met from production in other industries. Demand for input factors interacts with factor supply to determine factor prices. To this, price labour taxes, infrastructure tolls like the HVF, and other transport costs are added. The sum of these elements determines the product prices. The households own the input factors. When they supply these factors they are paid rent (capital) and wages. Supply of factors thus determines household income, which again influences final demand for goods and services. All goods and services can be met by local production or through imports from abroad or regional import.

As regards data, the general equilibrium models or CGE resemble greatly the input-output models, they are typically based on a SAM in monetary terms. Their main difference is how the economy is described with regard to production and demand. In a CGE model, the production is described explicitly through production activities, in which case the Leontief technology can be replaced by more complicated production activities, which are able to include substitution effects. As regards the demand, the consumption elasticities and substitution effects are described according to the definition of the utility functions.

Similarly to the input-output models, the strength of the general equilibrium models is a good description of the causal relations in the economy and the advantage that substitution effects are addressable. At the same time, it is a weakness of the general equilibrium models that a large number of elasticities are assumed to be available.

8.1.1.3 Dynamic macro-economic models

This type of model, which is represented by ADAM in Denmark and by ISMOD in Sweden are dynamic non-spatial macro-economic models. The two mentioned Scandinavian models are designed around error-correction models estimated from long national time series. In that way, the models include dynamic adjustment mechanisms. We will return to the formulation in Section 8.2.1. As regards the production, the models include a structure. The dynamic aspect is important as the best way to explain time series is when a dynamic adjustment to a long-term equilibrium is allowed.

When the economy experiences an exogenous shock, it takes some time before equilibrium is retrieved. Models allowing for this are better at measuring the strength of the examined relations. In a prognosis situation, the future shocks are not known, but it is assumed that the expected value of the shocks is zero. Therefore, the current deviation from equilibrium is the only information about shocks that is included in a prognosis. After a number of years, maybe five to ten years, the effect will have died. On a long view, the dynamics of the model is thus not so important for the prognosis.
8.1.1.4 Cost minimisation models

The models try to find the best solution according to clearly defined alternatives by minimising system costs at various policy aims. The system has been used to describe flows of goods and equipment and energy consumption (Sundberg, 1993; Gielen, 1999). There are several problems in relation to these models. Partly they are more normative than describing, which is not in harmony with the present need for a model. Furthermore, there is no integration with other economic activities and the demand aspect is exogenous.

8.1.1.5 System dynamics models

In system dynamics models (SDM), relations and exchanges between economic sectors, agents and production factors are modelled explicitly using difference equations. Difference equations describe changes over time for some entity in a given sector as a function of variables from other sectors. The system of difference equations are integrated in ‘appropriate’ sequential steps. The models are constructed in a cause-and-effect structure with positive and negative feedbacks between the sectors and that the systems’ dynamics are simulated. An example of such a dynamic system is found in van den Berg and Nijkamp (1994).

The number of details with respect to sectors, zones, and factors is very low and simplified due to the complexity of the model and the stability of the complete dynamic system. The functional relationships between the important variables of the model are determined using relevant literature and specific studies. Some parameters of the models are sometimes calibrated using “trial-and-error”. The empirical basis for the functional relations is often weak.

The main purpose for an SDM is not quantitative precision, but a wish to describe qualitatively the evolution and reactions in an economic system. A dynamic model is thus best suited to compare different policy approaches rather than to provide quantitative outcomes of the policies. One part of the SCENES model is an SDM. The European ASTRA model (Schade and Doll, 2005) is similarly a SDM model. This model has been applied to analyse effects of introducing heavy vehicle fees in the EU.

8.1.1.6 Time series models

Time series models are developed upon historical trends that are extrapolated into the future. For these models, a large number of econometric methods exist, but in transport models much simpler methods are often applied. A time series model concentrate on partial economic description and is thus not subject to any requirements about economic balance. Time series models may in some cases not even be monetary, because the variables can be physical variables in weight or volume.

One time series can be described by other time series used as explanatory variables in a functional relation. However, the models are often descriptive rather than normative. As such, these models will have difficulties in explaining consequences of large changes and policies that are unprecedented because they are partial without equilibrium features.
The models are often formulated in aggregate terms to avoid difficulties related to more disaggregated variables. Normally very long time series (many observations) are required to estimate the models. On the other hand, the models will give better predictions of future changes compared to models estimated on cross section data.

8.1.1.7 Zone-rate models
Zone-rate models estimate demand for transport based on simple indicators. Zone-based data such as number of firms, work places, houses, households, etc., are used to formulate statistical relations for production and household demand. These models are generally applied when data are sparse or weak or when resources for model development are a constraint.

8.1.1.8 Overview
A summary of the main characteristics of the different model types is provided in Table 8.3.

<table>
<thead>
<tr>
<th>Model</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input-output</td>
<td>- Possibility for feedback effects</td>
<td>- Leontief technology</td>
<td>Medium/Large</td>
</tr>
<tr>
<td></td>
<td>- Price equilibrium</td>
<td>- Data requirements high (SAM matrices)</td>
<td></td>
</tr>
<tr>
<td>Computable general equilibrium</td>
<td>- As with I/O</td>
<td>- Data requirements high (SAM matrices)</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>- Flexible technology</td>
<td>- Determination of elasticities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Flexible description of demand side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic macro-economic models</td>
<td>- Well documented and validated</td>
<td>- Not spatial</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td>- Fine dynamic relations (ECM)</td>
<td>- No feedback from transport sector</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Consistent with official forecasts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost minimising models</td>
<td></td>
<td>- Normative rather than descriptive</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- No causal relationships</td>
<td></td>
</tr>
<tr>
<td>System dynamics models</td>
<td>- Dynamics is integrated</td>
<td>- Bad or no causality</td>
<td>Medium/large</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Weak international experiences</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Weak empirical basis</td>
<td></td>
</tr>
<tr>
<td>Time-series models</td>
<td>- Dynamic</td>
<td>No causality between sectors, etc.</td>
<td>Small</td>
</tr>
<tr>
<td>Zone-rate models</td>
<td>- Simple</td>
<td>No causality between sectors, etc.</td>
<td>Small</td>
</tr>
</tbody>
</table>

Table 8.3: An overview of the main model types

If real causal economic relationships are central, input-output or computable general equilibrium models are the appropriate models to use. However, the model complexity of these models is large due to the demanding data requirements and due to difficulties in solving the models. This is a particular problem for CGE models.

Another difficulty embedded in the CGE models is the elasticities of substitution, which often have a weak empirical foundation. This is in favour of the input-output models using a simpler model approach. The general equilibrium concepts are necessary to include if the substitution between, e.g., different production inputs or demand is important.
Both input-output and CGE models allow for feedback mechanisms, where changes in transport costs influence economic activity.

8.1.2 Input-output and SCGE models
Calculation of production and demand must be based on spatial input-output models. Prognosis of economic growth can be based on the macro-economic dynamic models. In the following, some difficulties and possible ways of dealing with this will be described.

8.1.2.1 Coupling economic activity and transport costs
It is relevant to look at the coupling between economic activities and transport costs, because this is a link that is often used in relation to transport modelling. The question of this coupling is straightforward in most of the models mentioned in Table 8.3, because prices of transport can be determined exogenously. This, however, is not the case in economic modelling.

Modal split and route choice are parts of a separate traffic model similar to the approaches many European national and international models such as SAMGODS (Sweden), NEMO/PINGO (Norway), and the international STREAMS, SCENES, ASTRA and NEAC models. The conversion between monetary terms and physical measures, e.g., in tonnes, can be included in both the economic models and in the traffic model. The international models provide production and consumption matrices in tonnes as output of the regional-economic models of these model systems. In SMILE and STREAMS, these are converted to OD matrices using logistic sub-modules.

The traffic model establishes an equilibrium in the transport system, from where transport costs can be derived. Secondly, the economic model determines the price equilibrium given transport costs. The coupling between these two equilibrium systems is a specific question that should be dealt with carefully. The following approach can be used to deal with this:

1. Set initial transport costs in the traffic model;
2. Use the transport costs to calibrate the economic model in the base year;
3. Define the policy scenarios in the traffic model;
4. Run the traffic model in the new policy scenario based on the commodity flows determined in 2;
5. Use the new transport costs derived from 4) in the economic model to find the new equilibrium;
6. Use the resulting commodity flows to run the traffic model;
7. Iterate between 5) and 6) until a conversion requirement is fulfilled.

It is probably reasonable to stop after one or two iterations because higher order changes in transport costs are minimal as described by Romp and Oosterhaven (2002).

The TEM-II Model for the Netherlands
The Transport Economic Model (TEM-II) is used to produce medium- to long-term forecasts of freight transport for the Netherlands. The model was developed by NEA for the Transport Research Centre (AVV) of the Ministry of Transport, Public Works and Water Management.
Development work on TEM-II began in 1991, and continued through the nineties. AVV have used TEM-II for a range of applications, including:

- Strategic long term planning;
- Medium term planning and monitoring;
- Large infrastructure projects;
- Various corridor and cost-benefit analyses.

TEM-II uses an input-output based demand model to forecast transport flows by mode on an annual basis. TEM-II does not contain detailed networks for assignment, but freight demand predictions from TEM-II are assigned using the Dutch National Model System (LMS).

The TEM-II model uses three modes: road, rail and inland navigation/sea. Note that intermodal movements are not distinguished in TEM-II. In addition, eight types of transport flows are defined to distinguish the wide range of national and international transport flows that pass through the Netherlands:

- Pure national transport;
- Import/export by sea through Dutch ports;
- Import/export by sea through foreign ports;
- Import/export by land;
- Trans-shipment trade through Dutch ports;
- Trans-shipment trade that competes with Dutch ports (e.g., uses Belgian ports, then crosses NL);
- Transit flows using inland waterways.

In terms of zoning, 54 regions in the Netherlands are used, and 77 in other countries. The system architecture used for TEM-II is defined in Figure 8.5. Below each of the modules is described in more detail.

**Economic Modules**

The economic modules consists of an input-output module, a transformation module, and a regionalisation module. In the input-output module, a base-year national input-output table is updated to the forecast year. This is achieved using sectorial economic data on added value, consumption, import, export, investment, and public material expenditures. The transformation module is used to link the sectorial data from the input-output model to the 52 commodity groups distinguished in the model. Value to volume ratios are then used to convert the production matrices into tonnes. The regionalisation module is used to distribute the gross production, export, and consumption across the regions of the Netherlands. This is achieved using regional shares of employment and population.

**Trade Module**

The trade module is used to distribute the average growth factors for import and export for all international flows. The model also distributes the international trade flows using a gravity model.
The explanatory variables are national production and consumption, distance, and a dummy variable for trade relations.

**Economic Linkage Module**

This module is used to link the transportation data to expectations about economic development from the economic modules. For domestic flows, the regional production/attraction information is upgraded before distribution.

**Container and Port Competition**

This module determines the containerised share of international freight using user-defined factors. The port competition module determines the share of port use dependent on the accessibility of the port and the total flows transferred through the port.

**Mode Split**

The mode split is based on the base year mode split by OD pair and commodity group. The default option is to use these values. It is possible to make changes to level-of-service on an OD basis in the forecast year by implementing changes in level-of-service. However, networks are not defined in TEM-II and so there are no capacity restrictions affecting on the predicted mode split.

### 8.1.2.2 Production

Input-output models have normally been based on sector to sector input-output tables. From a theoretical and empirical point of view, it is better to base the models on “make and use” approaches (Madsen and Jensen-Butler, 1999) with sub-models for sector to commodity and commodity to sector flows. Such models will be even closer to the true theories of production and consumption and in parallel be more transparent and much easier to formulate. The make-use approach has been chosen in SMILE, PINGO, and SAMGODS.
In relation to the description of the production industries, it is necessary to establish credible links between the economically based standardised classification of commodities (the SITC classifications) and a classification that is meaningful in freight transport. The basis for the economic classification is often not important from a transport point of view. It is important that the classifications are meaningful seen in relation to the so-called ‘logistical families’ as discussed in Tavasszy et al. (1998a). This makes it easier to make a link to a logistical modelling. The specific choice of classification may differ from model to model and country to country depending on the data quality and detail.

A very crucial link is the differences between production and demand. Production is undertaken within economic sectors, whereas demand is for commodities. A conversion between sectors and commodities is thus necessary. In the Scandinavian PINGO and SAMGODS a matrix containing the conversion factors has been established. Fosgerau and Kveiborg (2004) has shown that these conversion factors are quite stable over time.

Another important distinction is that commodities are used both as intermediate input to other production sectors and as final demand. Some models make this distinction explicit (e.g., the VTI/TRP module of SAMGODS using an I/O approach), while others do not distinguish between the two uses (e.g., the Norwegian PINGO model). PINGO is a CGE model and as is typical for these models of macro-economic trade, the consumption of commodities is simply modelled as demand for a composite good, which through commodity agents or explicitly modelled in the production or demand functions is conveyed from production zone to consumption zone.

It is furthermore important to be able to distinguish between service production and production of other goods, since service production in itself does not generate transport of its output. However, it is important to include, because service industries demand input of physical commodities and because changes in transport costs may influence the balance between service and other production.

The transport sector has traditionally been modelled in four different ways:

- Using a distribution model as it is done in SAMGODS;
- As an independent sector like in the SCGE approach in PINGO;
- Using the Iceberg formulation, where the value of the good diminishes as the good is moved on (Samuelsson, 1952);
- An inverse iceberg formulation.

The fixed distribution approach does not provide endogenous transport prices, but use fixed transport margins throughout the modelled system. The SCGE approach with separate transport sector(s) produces transport through a production function. A third approach is the Iceberg-formulation, where the good diminishes when it is conveyed. In certain very special situations, this may lead to inconsistent solutions such as the paradox, where increasing transport costs may lead to increasing demand because a fixed part of the good “melts” away.
The inverse iceberg approach means that production costs increase with a fixed rate during transport.

Input-output models are typically based on a restrictive and fixed Leontief technology. This approach means that there is no substitution between commodities even when prices change. There is in contrast almost no restrictions on the generality of substitution effects that can be included in the SCGE models. An often-applied approach is the constant elasticity of substitution (CES) formulations, which allows substitution.

### 8.1.2.3 Demand

Household demand is in many economic models split on a number of demand agents including for example households, industry, and the public sector. In some models demand is specified using production functions and utility functions, where both production and consumption is variable. This means that there may be changes in the demand by one specific agent in a specific region. However, it is common to assume that the population is immobile, which implies that final demand for goods is close to being immobile. The main disadvantage of having immobility is that the second- and higher order effects of changes in one specific sector will be underestimated. The alternative of having mobile input factors is not encouraging though, as this is difficult to handle.

### 8.1.2.4 Import and export

In many national accounts, there is a detailed account of import and export both with respect to the domestic sector and the foreign import/export country. When focus is on one specific country or even a region within a country the composition of consumption, population costs, etc., in other countries or regions may not be known to the modeller. This is the reason for the choice of much simpler approaches in describing import and export. In the literature, three general approaches have been used:

1. Foreign countries or other regions are included through port zones;
2. Import and export are calculated to and from other sub-regions in other countries or regions. Proxies are used to determine the split of demand and of production;
3. An economic model provides the commodity flows between countries or regions. One such example is the CGEurope model used in the TRANS-TOOLS model.

The third method listed here is rather complex. It involves a prior economic model add-on that takes care of international (or interregional) trade. This requires a very large amount of data. Whether import and export should be handled in one way or the other depends on the objectives of the models. Port zones are unsatisfactory if the modelling of international transport is important.
8.2 Estimation, calibration and validation

Some economic models are based on statistically estimated relations – typically, time-series models – other models are theory-based, where relations can sometimes be estimated, but sometimes there are no data that can be used to estimate the relations. Calibration is a method that is applied in these latter cases. Parameters of the relations are manually changed until the relations in the model replicate a base of observed values. The calibration is performed step by step or simultaneously across all relations in the model. It is preferable to have estimated relations, but this is not always possible. In models, there may be both estimated and calibrated parameters. Most models contain a number of relations that are related to each other. It is valuable to validate the model ability to replicate the observed state of the relevant variables. The validation of models is not structured in the same way as both estimation and calibration. Validation of the models follows from the use of the models on different projects, policy questions. The experience gained from the use of models and comparison of key output with output obtained in other studies and models serve this purpose.

This section focuses especially on the estimation techniques since these are the most theoretically developed and founded. We include a subsection on the calibration and describe the process used in the computable general equilibrium models, where calibration is very useful. Finally, there is a short section on validation, which complements the description in Section 4.4.

8.2.1 Estimation methods

There is a long tradition in economics of using statistics (or econometrics as it is called in economy) to establish relations between dependent and explanatory variables. Many of the parameters that are estimated have a specific interpretation as elasticities. The section here uses this as the basis for explaining the different methodologies. The methods described can be used to estimate any other type of parameters in the models. Examples are position parameters (constant terms) and level parameters.

8.2.1.1 Elasticities

Elasticities are important in most economic models. Elasticities are used to describe behaviour by the individuals (households, persons, firms, etc.). Elasticities in economic models are substitution elasticities, price elasticities, and income elasticities indicating percent changes in a variable if, e.g., the price/costs or income change by one percent. The elasticities play a crucial role in economic models as well as in the passenger and freight transport models described in Chapter 6 and 7. An important task is thus to find the size of the elasticities. Two recent reviews by Goodwin et al. (2004) and Graham and Glaister (2004) describe elasticities found in the literature since 1990.

Estimating elasticities

An important tool to find elasticities is econometric (statistical) estimations. Two main approaches are used: time series and cross section. The choice of method depends on the type

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4 ‘Manually’ also includes a systematic search for relevant parameter values. The difference is that the obtained parameter values cannot be tested for statistical significance in a calibration search.
of data available. Of the 175 reviewed estimations of elasticities provided by Goodwin et al. (2004) they count 83 time series, 77 cross sections/time series and 15 cross-section types of data. The estimations and equations used are static (89), dynamic (86), constant elasticity (138), linear (26), other (8), OLS (113), full information maximum likelihood (19), GLS (18) and other (19). The pooled cross section/time series tend to give lower elasticities with the dynamic formulations. The different estimation methods also give different results, but there were no systematic pattern in the differences between methods. The functional forms used in the estimations are:

- Log-linear;
- Linear;
- Non-linear;
- Semilog;
- Box-Cox.

According to Goodwin et al. (2004), there is no consistent pattern in differences in the results from the different functional forms. There may be an indication that the log-linear form gives lower elasticities than other non-linear forms with respect to income.

The model specifications give significantly different results, though without a systematic pattern. The models used in the reviewed studies are:

- Partial adjustment;
- Error correction models;
- Inverted v-lag.

### 8.2.1.2 Time-series estimation

Time series estimation is perhaps the most common statistical method in economics. There is a long tradition for gathering economics data over time and many national account data exist for very long time periods in most countries. The standard approaches are described in many text books. Some examples are Davidson and MacKinnon (2003), Lütkepohl and Krätzig (2004), and Clements and Hendry (1998). These references should be consulted for the specific modelling and estimation techniques.

A basic time-series (multiple regression) model includes relations of the following type:

\[ y_t = \alpha_t x_t + \varepsilon_t, \]

where \( \alpha \) are parameters of the model and \( \varepsilon \) is a random variable with a normal distribution. The parameters are estimated using ordinary least squares (OLS), when basic assumptions are fulfilled.

The basic linear model can be generalised by allowing the functional form to deviate from the linear as for example log-linear, Box-Cox, Cobb-Douglas, and other even more general functional forms:
$Y_t = h(\alpha, X_t) + \epsilon_t$.

The non-linear models are estimated using generalised least squares (GLS) or maximum likelihood if the disturbances are normally distributed.

An often-applied approach in economic models is autocorrelation where the dependent variable is explained by lagged observations:

$Y_t = \alpha X_t + \sum \delta_l Y_{t-l} + \epsilon_t$.

The most widely used test of autocorrelation is the Durbin-Watson test based on autocorrelation in the least squares residuals.

Another dynamic model includes a trend in the model relations:

$Y_t = \alpha X_t + \delta t + \epsilon_t$

Specific care must be taken in the estimations, when the relations are dynamic. If both the dependent and the explanatory variables contain a trend, we may face a spurious regression, where there is a very good model fit, but the relation may not mean anything and there is in fact no relation between the two variables except that they both contain a trend. To avoid such problems it is necessary to ‘detrend’ the series before estimating the model.

The approach in these cases is to check whether the time series of the different variables are co-integrated. A time series is integrated of first order if the new series of first order differences: $y_{t} - y_{t-1}$ has disturbances, which are normally distributed\(^5\). Two series are co-integrated if they are both integrated of order one and there is a significant relation between the two series of first-order differences.

When two series are co-integrated, it is very common to formulate error-correction models, where the long run development in the dependent variable is complemented by the short run differences between the co-integrated variables:

$y_t - y_{t-1} = \alpha + (\beta - 1)(y_{t-1} - \lambda x_{t-1}) + \gamma(x_t - x_{t-1}) + \epsilon_t$,

where the term $(\beta - 1)(y_{t-1} - \lambda x_{t-1})$ is called the error-correcting term and measures how much the long run relationship between the dependent variable $y$ and the explanatory variable $x$ are from each other. The parameters of the model determines the sensitivity to both the long run, $\beta$, and the short run, $\gamma$.

\(^5\)To test for this we need to check whether the series has a ‘unit root’, which is done using the Dickey-Fuller test. We will not go into details about these technical approaches here, but refer to the text books on these estimation techniques.
There are many models based on time-series relations. The models are constructed upon a number of relations, embedded in each other, such that the dependent variable of one relation is included as explanatory variable of another relation. Each relation is estimated independently using independent data as in the descriptions above. However, it is more common that blocks of relations are estimated simultaneously in for example seemingly unrelated regression models, systems of demand equations or vector autoregressive models (Davidson and MacKinnon, 2003). They are generally termed Simultaneous Equations Models. The interdependence between the different relations will influence the estimation of the relations and the test statistics used. The problem is that the disturbances in the relations are dependent and the estimated parameters could become inconsistent. Some of the methods used to get consistent estimates are full information maximum likelihood (FIML), using instrumental variables, which are independent or rewriting the system of equations or relations into a fully recursive model, where each relation is estimated independently using OLS. However, it is not always possible to reformulate the system into a recursive system. It is thus necessary to use the generalised least squares methodologies with instrumental variables, or two- or three stage least squares. These different approaches are all described in the many texts books on time series estimation.

A typical simultaneous equation model is the ADAM model of the Danish economy (Dam, 1995), where most of the relations are formulated and error-correcting equations. Similar models exists in Sweden (ISMOD), the UK (Garratt et al., 2003).

A basic problem of this type of models is that the estimated and to some extent independent relations may be rather inaccurate because they lack some of the equilibrium mechanisms included in the general equilibrium models. Another criticism is that the system of equations is not theory based – each independent relation can be based on theory, but the dependency with other relations may not be. The interpretation of the results and the parameters should be done carefully. The positive side of the models is that they are estimated on historical observations of the relations, which are tested statistically.

Time series data have been used by several studies to estimate linkages between infrastructure investments and productivity. The results of such estimates are called “output elasticities” measuring changes in production due to changes in investments. Johansson et al. (1996) have made a review of results from different countries. The differences are quite large and results from these types of studies are notoriously affected by spurious correlation, because many of the included factors grow smoothly over time and selecting any two of them will always show a strong statistical link. This is the reason for using the error-correcting models as described above. The results derived from aggregated production function by Johansson et al. (1996) are summarised in Table 8.4.
TABLE 8.4: OUTPUT ELASTICITIES ESTIMATED ON TIME-SERIES DATA

8.2.1.3 Cross-section models

Data are not always available for longer time periods. This is particularly a problem in the New Member States, but can also be a problem concerning specific types of data in the old EU countries. Many countries collect specific data on for example expenditure at various time intervals. Such data are rich on information across different types of individuals (e.g., persons, households, regions, or countries). Using cross-section data, the behaviour of the sample group can be coupled with variables that are characterised by the differences across the (sample) population.

Cross-section data and estimation of cross-section models are very similar to the general estimation of relations in traffic models. The techniques described in the chapters concerning the transport models are equally applicable for cross-section based economic models. We will thus not spend much time on them here. The cross-section approach is more interesting in relation with time series in so-called panel data. We will thus discuss this particular type of model in more detail next.

8.2.1.4 Panel data and pseudo panels

Panel data provide a rich opportunity to combine time-series and cross-section data to examine issues that could not be studied using either time-series or cross-section data alone. Panel data require data collection on the same individuals (the panel) at several points in time to follow the changes (if any) in behaviour. Panel data collections are normally rather expensive, but they often contain a large number of individuals. The panel is often followed a limited number of periods. It is thus not always possible to analyse changes over a long period. It is possible to observe discrete changes of state. This can be changes such as location or car purchase.

Due to the often limited time periods, it is difficult to apply the normal time series estimation techniques. Hence, specific panel data methods are applied. Typically, two types of models are used: a fixed effects model and a random effects model. Let $y_i$ and $X_i$ be the $T$ time observations of the $i$th unit, and let $e_i$ be the associated $T \times 1$ vector of disturbances, further let $u_i$ be the random disturbance characterising the $i$th observation and assume it is constant over
Examples of both types of models are used, e.g., in Lyk-Jensen (2005), to estimate an international trade model.

Fixed effect model:  
\[ y_i = i \alpha_i + X_i \beta + \varepsilon_i. \]

Random effects model:  
\[ y_{it} = \alpha + \beta' X_{it} + u_{it} + \varepsilon_{it}. \]

The fixed effects model assumes that differences across units can be captured in differences in the constant term (\( \alpha \)). This model is reasonable when we can be confident that the differences between units can be viewed as parametric shifts of the regression function. It considers only the units within the study and is appropriate if the sample is exhaustive. In many cases this is not fulfilled. It is then more appropriate to view the individual-specific constant term as randomly distributed across the cross-sectional units. We then use the observations from different time periods to estimate the model.

It is difficult to judge which of the two types of models that should be applied even though the random effects model has some intuitive appeal. However, there is often no justification for treating the individual effects (\( u_i \)) as uncorrelated with the other regressors (\( x_{it} \)) as is assumed in the random effects model. The random effects model may therefore suffer from inconsistency due to omitted variables. The Hausman test, see Hausman (1978), can be used to test the independence of the regressors and the individual effects.

In most countries, panel data collection is not conducted. Many countries do have repeated surveys of various kinds such as the UK based Family Expenditure Surveys or the national travel surveys describing respondents travel choices (see, e.g., Stopher and Stecher, 2006). These surveys do not constitute true panel data, but Deaton (1985) introduced a so-called ‘pseudo-panel’ approach, where individuals or households (units in the above used terminology) are grouped into cohorts, which are defined on the basis of common shared characteristics. The cohorts are then traced over time. Averages in the cohorts are used as observations in a panel on which the models mentioned above can be estimated. Although the data are not a true panel, since the individuals included change from year to year, the individuals within each cohort have similar characteristics in each time period, so that the cohorts can be treated as if they were observations of the same individuals over time. Thus the term ‘pseudo-panel’. Dargay (2001 and 2002) have used pseudo-panel data to estimate determinants of car ownership in the UK.

8.2.2 Calibration issues

The general equilibrium models contain a large number of relationships that need both specific parameters or elasticities and a number of so-called position parameters. For example the \( a \), which is the position parameter, and \( \beta \), which is the elasticity of \( y = ax^\beta \).

The elasticities and the position parameters could in principle be estimated using separate data sources (any of the approaches described in Section 8.2.1 could be used, obviously depending on the type of equation that is used in the CGE model). However, in practise this would be too demanding and time consuming. Instead elasticities from other studies and analyses are
employed. An important elasticity is on the labour supply, which is used in many models. There seems to be consensus about this elasticity at a level of 0.2 (Kreiner et al., 2004; Parry and Bento, 2001; Parry and Small, 2005). Position parameters on the other hand cannot be found in the literature. The function of these parameters is to ensure that the CGE model can replicate the base-year data on which it is constructed.

Another type of calibration is when estimated parameters are adjusted so that, e.g., an aggregate measure is found. An example is when an aggregate value is known and more disaggregate values of a similar type has been estimated. If the aggregation of the disaggregate values does not meet the aggregate value an adjustment is made. Sometimes this type of calibration is directly included in the estimation procedure by adding it as a constraint.

In TRANS-TOOLS, many parameters are identical within certain clusters of regions. One cluster is the Scandinavian countries and another is the Baltic countries, which are treated similarly in the model calibration. This approach is chosen because of the large number of possible combinations of regions and commodities. Country (and commodity) specific parameters would improve the reliability of the model, but the work to do this was too much to be carried out within the project.

8.2.3 Validation
This issue has already been considered in Section 4.4 for the general case. For time-series models a very specific type of validation can be done; back-casting. The model is run using historical values of the input variables. The resulting output variables are compared to the historical observations of these variables. It is both the values of the endpoints and especially the evolution of the output that is interesting to look at. The model should at no point deviate more than one (sometimes two) standard deviations of the historical observed variables.

8.3 Specific modelling areas
Economic models can in relation to transport focus on the driving forces behind transport demand, and especially how the driving forces are influenced by changes in for example the regulation of transport, changes in the tax system or other regulatory changes that can have effects across sectors. The models can sometimes include differentiation on different modes, when this is expected to be important for the changes in economic activity or may influence household consumption in different ways. However, the models will mostly not include such differentiation, but rather use generalised costs functions aggregated over all modes.

Economic models can in some cases include spatially different impacts on choice of house location. This is done partly in relation to land-use models. When economic models specifically include housing prices the models can focus on changes in demand for transport in different regions. There can also be cases where the economic model specifically addresses changes in demand for different types of activities. For example where the model describes the choice between labour and leisure. Increasing labour supply may lead to a declining demand for leisure trips. These effects are only in very rare cases the specific focus of the model, but can sometimes be derived from an economic model.
8.3.1 Taxation and charging

Economic models are well designed to address questions about economic instruments such as taxes, charges, and fees. The key point in economic instruments is that they influence demand. The economic model focuses on this specific link, but in many cases the focus goes beyond that. Economic models bridge between different sectors of the economy and describe linkages between the direct impact where the economic instrument is introduced in other markets. Examples of such economic models are the spatial general equilibrium module of TRANS-TOOLS, the Dutch RAEM (Oosterhaven et al., 2001) and the Norwegian PINGO (Ivanova et al., 2002). A common feature of these models is the inclusion of supply and demand effects and especially the possibility to analyse effects of spending the revenues from the charging instrument.

Theoretical analysis of the implications of taxes and charges for other sectors, households, and the government is often addressed using very specific partial economic models. The models are sometimes calibrated to specific areas or are generic to highlight the interrelations between different sectors. Examples of generic models are Verhoef (1996) and Parry and Bento (2001).

There are examples of economic models used to evaluate the welfare effects of road pricing. The objective of these models is to address how increasing prices on car transport influence other markets and the labour market in particular. The models analyse

- Congestion using rather simplified speed-flow curves;
- Other externalities through marginal external costs;
- The labour market, supply and demand;
- Household utility, which is increasing in leisure and commodities;
- A welfare function, typically of the additive kind (the utilitarian approach).

In some cases, the models can include a specific public sector collecting taxes and redistributing revenues. The models are sometimes including general equilibrium properties and sometimes they are partial equilibrium models. There may be a spatial resolution, but this is not always necessary. It is necessary to include all areas that are influenced (in economic sense) by the road charges to be able to calculate welfare effects.

There are some recent examples of models with the specific focus on road pricing and welfare effects. The Danish Economic Council has evaluated a road pricing system for Copenhagen using a partial equilibrium model (Pilegaard et al., 2006). The model is based on Parry and Bento (2001), who outline a theoretical model that can be used to evaluate welfare effects of road pricing including the revenue effects. However, most analyses of this kind published internationally are generic and aimed at analysing the properties of road pricing schemes compared to other schemes. The theoretical models are supported by numerical examples, but these examples can only in very rare cases be directly used to evaluate a particular pricing scheme. The model approaches are very useful in providing insights and can as in the Danish example mentioned above, be adapted to specific schemes by using real data.
8.3.2 Changes in trip patterns and location effects

Trip patterns, location choices and other similar spatial consequences of policy instruments are often treated in economic models as part of land-use-transport-interaction (LUTI) models, where the spatial consequences are treated by other parts of the model system and not by the economic model. However, there are some (mainly theoretical) contributions, where the spatial consequences are being included directly in the economic model. Most of these models are coming from the so-called Economic Geography inspired by Krugman (1993) and Fujita et al. (1999).

The effects of location and accompanying trips patterns have been the subject of very many theoretical journal articles. An example is Anas and Xu (1999), who use a CGE model to analyse the interrelation between congestion tolls and the location of firms and households. They find that the centralising effect of households moving closer to the centre dominates the decentralising effect of firms moving closer to their customers. The location effects are long-term changes. Analysis of long-term effects is addressed by CGE models where the system is assumed to be in equilibrium after inferred changes in policies. This makes these models particularly well suited to address these types of questions.

Unfortunately, most of the models have quite artificial descriptions of the city. Often monocentric or polycentric cities are used to describe the spatial characteristics of the city (for example Eliasson and Mattsson, 2001; Anas and Kim, 1996; Modarres, 2003). These models may use data from a real city to calibrate the model, but the results do not generally describe how the policies analysed will change the city in reality. An exception is Modarres (2003), who analyses the location of major firms and their work forces in Los Angeles County. The generic models provide insights in the mechanisms, but not real quantitative results. There is still work to be done before these models can address the actual outcome of specific policies in specific (urban) areas.

8.3.3 Distributional effects

Who will be affected by certain policies? This is a question that is often very relevant to the policy makers. Sometimes this question is even more in focus than the overall outcome of the policy. The influence on different income groups or different regions can in the end determine the choice of implementation. (Spatial) economic models can address this question directly by including different regions and/or different types of households in the analysis. The welfare or income effects and the behaviour of the different groups are often theoretically easy to incorporate. The possibilities are determined by available data. It is necessary to have data on the details addressed by the model. If such data are not available it is only possible to get general results. However, it is possible to distribute effects according to more general information. The regional distribution can sometimes be obtained by a distribution based on the number of households, the number of work places, or the specific industrial structure in the regions.
International and regional trade models include the differentiation needed to address spatial distribution effects. Most of these models include distribution according to industry or economic sector, because of the different types of transport demand in different industries. Some of the models include different types of households as well. TRANS-TOOLS include all these categories, but naturally at a very general level. Chapter 10 will put more focus on this issue.

### 8.4 Interaction with transport

In order to get a proper description of the transport system, most economic models are linked with transport models. The primary interactions between the economic model and the transport model can be seen in Figure 8.6. The transport models provide an aggregated description of the transport system to the economic models, which on the other hand provide growth rates for the number of trips.

**Figure 8.6: Interaction between economic models and transport models**

The transport related economic models may describe the total number of trips (trip generation) or the total number of trips for each pair of zones (trip generation and distribution). Depending on formulation, the specific interactions will take different forms. These are described in Section 8.4.1 and 8.4.2.

Common for all formulations is that they are able to reflect issues, which are included in the transport model. For instance, if the assignment model includes effects of congestion in the form of longer travel times and increased uncertainty about the travel times these effects are included in the generalised costs of the assignment model and thereby in the accessibility measures. The effect of congestion on travel time is determined in the transport model, whereas the effect of changes in travel time (accessibility) on the number of trips or on other regional effects is determined in the economic model. The same applies for, e.g., the effects of road pricing, where the transport model determines the effect of the additional costs (includes possible differences in attitude towards road pricing compared to other costs), whereas the economic model determines the effect on the total number of trips as well as on economy and on society in general.
8.4.1 Interaction of economic model for trip generation

If the economic model does not include a spatial aspect, the description of accessibility should be on a rather aggregated level, i.e., one measure aggregated over all routes, transport modes and zones. If the trip distribution and the mode choice are formulated in a discrete choice model with a hierarchic structure, the accessibility measure might be the sum of utilities generated from the model estimation, see, e.g., Ben-Akiva and Lerman (1985). Since the discrete choice model include information from the assignment all effects of this model are included in the sum of utility.

For disaggregated economic models, e.g., with spatial differentiation, detailed measures of accessibility are needed from the transport model. The most detailed measures may be obtained from the assignment model (route choice), where accessibility may be formulated by the generalised costs by each route, mode, and pair of zones (see Chapter 7 and 9). For more aggregated measures of accessibility, sums of utility may be obtained from different levels of the hierarchic structure of the discrete choice model, as described above.

After determining the growth in number of trips, this information is fed to the trip distribution of the transport model. For transport models with capacity dependent travel times and costs, it might be necessary to have several loops between the economic model and the transport model before equilibrium is reached.

8.4.2 Interaction of economic model for trip generation and distribution

When the economic model includes spatial effects and describes both the total number of trips and the distribution of trips between zones the measures of accessibility should be aggregated by route and mode. Such measures may be obtained from the sum of utilities generated from the estimation of the discrete choice model describing mode choice.

After determining the growth in the number of trips and their distribution among pairs of zones, the information is fed to the mode choice model. When the transport models include capacity depended travel times and costs it might be necessary to have several loops between the economic model and the transport model before equilibrium is reached.
9 Assignment modelling

Assignment models assign the transport given as trip matrices onto the transport network. The transport demand are hereby assigned along routes in the network. As the routes are not known a priori, the model needs a route choice generation principle. Some assignment models describe congestion in the network. In this case, the model also has to re-calculate and assign transport in order to find an equilibrium between demand (route choice) and supply (speed-flow relationship) in the transport network. In general, route choice models therefore consist of three main algorithmic components;

1. Route choice set generation
2. Traffic assignment
3. Equilibrium scheme

Given that an assignment model has these three main ingredients (demand, supply, and network) we can characterise different models using Table 9.1 (Cascetta, 2001).

<table>
<thead>
<tr>
<th>Supply factors</th>
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<tbody>
<tr>
<td>Type of service</td>
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<td>Congestion effects</td>
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<th>Demand factors</th>
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<td>Demand segmentation</td>
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<td>Demand Elasticity</td>
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<td>Path Choice Behaviour</td>
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<td>Path choice model</td>
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<th>System approach factors</th>
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<tr>
<td>Intra-periodal Variability</td>
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<td></td>
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<tr>
<td>Demand-supply interaction</td>
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<td></td>
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</tbody>
</table>

Table 9.1: Classification factors of assignment models

Before getting into details, we will note that often in the literature, the assignment models are only described as the step in 4-step models, where a modelled OD matrix is distributed in the road network. However, there are several main functions and use of assignment models:

1. Distribution of OD matrices in the road network.
2. Estimation of travel resistance between zones as input to the models of trip generation, trip distribution, and modal split.
3. Modelling of route choice within models that estimate trip matrices based on traffic counts.

4. Helping with providing a qualitative knowledge on route choices.

The basic inputs required for assignment models are:

- Trip matrices expressing estimated demand. This may be a peak-hour (or two-hour) matrix and an off-peak matrix, or a more detailed segmentation into time periods. The summation of these matrices will be a 24-hour matrix;
- Principles or route selection rules thought to be relevant to the problem in question;
- Supply measured in generalised cost;
- A network, e.g. links and their properties. More advanced models may include nodes as well (intersections, stations, bus-stops, etc.)

A key component in the assignment process is to build route paths from each origin to each destination so that inter-zonal trips can be assigned to these paths. All methods used for this process are considerable approximations of the great complexity of observed paths taken by car drivers and public transport users.

In section 9.1, we discuss how to combine the above concepts into an assignment model. We conclude the section with a discussion on how to extend the basic single user class model to multi user class models and how to extend the static model into a dynamic model. Aspects such as congestion, reliability, punctuality, and capacity are discussed in sections 9.5 and 9.6.

The issue of scheduled assignment is left for the Sections 9.6 and 9.7 on public transport. A special challenge is the interaction between local, regional, and international traffic, since all levels interact on a single network. This is postponed for Chapter 12, which deals with the issue of linking models of different geographical scale.

### 9.1 Methodological overview

If we consider a fixed demand for travel in a given network, an assignment model has three stages with a cyclic structure. One is the supply given by links and speed-flow relations. A second is the route choice. And the third is the assignment algorithm. This section will describe these stages before we give an overview over complete assignment models, discuss extensions, and comment on software for assignment. A theoretical overview is given in Patriksson (1994), whereas overviews with a more practical focus are given in TRB (1994) and Thomas (1991). A more recent overview is given in Bell (1998).

#### 9.1.1 Supply

The supply-side of assignment models describes the transportation network. Traditionally, this has been built as mathematical graphs, consisting of links and nodes, whilst public transport models may include more complex network descriptions.
9.1.1.1 Supply, road links

The supply side of road network models describe the capacity and topology of links. The topology is given by the real world (except for level of detail), so the main input from the supply side is the effect of capacity on travel times. This is of course only relevant when capacity is included in the assignment model. The usual approach is to describe the capacity constraint through speed-flow curves, i.e., mathematical relationships between speed and flow. The general assumption when defining such a relationship is that the speed ($V$) with which the cars travel on a given road segment is dependent on the flow ($F$) of cars on the road section. The flow is defined as being the number of cars passing a given cross section of the road and is measured in terms of vehicles per time interval (e.g., cars/h). The relationship between speed and flow is assumed to have the shape illustrated by the bold line in Figure 9.1. According to this relationship, the speed on the road segment will decrease as the flow increases up until the point ($F_{cap}$, $V_{cap}$) where the flow has reached the flow capacity for the particular road segment ($F_{cap}$) and the speed has decreased to $V_{cap}$. At this point, the traffic has become so massive that the flow begins to decrease as the speed decreases, and theoretically, it is possible to reach a point at which the flow reaches zero as the speed reaches 0, i.e., the traffic reaches a condition of total standstill. The situation in which the speed is above $V_{cap}$ will be referred to as free-flow condition in the following, whilst the situation in which the speed is below $V_{cap}$ will be referred to as queue condition.

![Figure 9.1: The standard relationship between speed and flow](image)

Often, the curve which best approximates the speed-flow relationship is assumed to follow the shape of the BRP formula (Bureau of Public Roads, 1964).
Mathematically, the BRP formula follows the expression:

\[
V = \frac{V_f}{\left(1 + \alpha \left(\frac{F}{F_{\text{cap}}}\right)^\beta\right)^{\frac{1}{\alpha}}},
\tag{9.1}
\]

where \(\alpha\) and \(\beta\) are parameters unique to each road type.

The problem with this mathematical relationship is that below \(V_{\text{cap}}\), the relationship takes on the shape illustrated by the dotted curve in Figure 9.1. As illustrated by Figure 9.1, a one-to-two cardinality exists between speed and flow. A given measured flow can be the result of either slight but fast moving traffic or a very concentrated but slowly moving traffic. In car assignment modelling though, the speed-flow relationship under queue condition is very often greatly simplified by approximating it by a single queue speed (\(V_{\text{queue}}\)), illustrated by the horizontal line in Figure 9.1, which is given as a unique input parameter for each road segment.

This indicates that to produce a proper expression for speed-flow curves under queue condition, a different mathematical approach is needed. To accommodate this, the concept of density (\(D\)) needs to be introduced. Density is defined as the number of vehicles occupying a given road section, and is measured in cars per distance (cars/km). Density, flow and speed are related through the following relationship:

\[
D = \frac{F}{V} = \frac{\text{cars} \cdot h}{h \cdot \text{km}} = \frac{\text{cars}}{\text{km}}
\tag{9.2}
\]

Combining expressions (9.1) and (9.2) leads to a flow-density relationship as illustrated by the bold line in Figure 9.2, where the part below \(D_n\) is given by the speed-flow function from (9.1).
Figure 9.2: The standard relationship between flow and density

$F_{\text{cap}}$ is of course the maximum flow capacity of the road section while $D_m$ is the density at which the maximum flow occurs. The section of the flow-density curve to the left of $D_m$ thus represents free-flow condition, while $(D_m, F_{\text{cap}})$ is equivalent to $(F_{\text{cap}}, V_{\text{cap}})$ on the speed-flow curve. The flow-density curve on free-flow condition is often approximated by a linear relationship as illustrated by the punctured line in Figure 9.2 based on the BRP formula though, the curve needs to have the convex shape of the bold curve.

The section of the curve to the right of $D_m$ represents queue conditions with $K_{\text{jam}}$ being the maximum density possible. The point $(K_{\text{jam}},0)$ is equivalent to the point $(0,0)$ on the speed-flow curve, that is, total breakdown in the traffic.

As earlier mentioned, the free-flow part of the speed-flow curve is assumed to follow the BRP relationship. Based on this, the following will hold for the transition point $(F_{\text{cap}},V_{\text{cap}})$ between free flow condition and queue condition:

$$V_{\text{cap}} = \frac{V_f}{1 + \alpha \left( \frac{F_{\text{cap}}}{F_{\text{cap}}} \right)} = \frac{V_f}{1 + \alpha} \tag{9.3}$$

As the point $(D_m, F_{\text{cap}})$ is equivalent to $(F_{\text{cap}}, V_{\text{cap}})$, (9.3) leads to:

$$V = \frac{F}{D} \Rightarrow V_{\text{cap}} = \frac{V_f}{1 + \alpha} = \frac{F_{\text{cap}}}{D_m} \Rightarrow D_m = \frac{F_{\text{cap}}}{V_f} (1 + \alpha) \tag{9.4}$$

We have thus produced an expression for $D_m$ as a function of free-speed, the maximum flow capacity and the parameter $\alpha$. 

MOTOS
Regarding queue condition, the flow-density curve is normally assumed to be linearly decreasing. The relationship can therefore be written as

\[ F = A - BD, \]  

(9.5)

where \( A \) and \( B \) are parameters that can be written as

\[ B = \frac{F_{\text{cap}}}{K_{\text{jam}} - D_m}, \]

\[ A = K_{\text{jam}}B = \frac{K_{\text{jam}}F_{\text{cap}}}{K_{\text{jam}} - D_m}, \]

(9.6)

Combining (9.2) and (9.5) thus produces:

\[ D = \frac{F}{V} \Rightarrow F = A - B \left( \frac{F}{V} \right) \Rightarrow V = \frac{FB}{A - F}, \]

(9.7)

We have thereby produced an expression for the speed-flow curve under queue condition as a function of flow, maximum flow capacity, and maximum density.

An example of a recent application of the BPR formula (Horowitz, 1997), where the traffic in the opposite direction at two-lane roads is taken into account is seen below

\[ t = \begin{cases} t_{\text{free}} \left( 1 + \alpha \left( \frac{V + \gamma V_{\text{opposite}}}{V_{\text{Cap}}} \right) \right)^{\beta} , & \left( V + \gamma V_{\text{opposite}} \right) < V_{\text{Cap}} \\\n t_{\text{queue}} , & \left( V + \gamma V_{\text{opposite}} \right) \geq V_{\text{Cap}} \end{cases}, \]

(9.8)

where \( t \) is travel times, \( V \) flows, and \( \gamma \) an additional parameter.

### 9.1.1.2 Supply, public transport

The supply-side in public transport networks is much more complex than car transport networks. The emerging issue of GIS (Geographical Informations Systems, Nielsen et al., 2001) eases however the coding of the supply side of public transport assignment models. The first use of GIS in connection with transport models utilised simple link-node topologies to describe transport networks. All subsections of routes were described by links and nodes similar to mathematical graphs, although they might share the same road in the physical network. The data describing the links contained information on the from-node and to-node, while data describing the associated links were not maintained equally for the nodes.
This made it difficult to implement efficient network algorithms that ran directly on top of the GIS data, as the whole calculation graph had to be rebuilt whenever it was needed.

Using the same approach, primitive modelling of public transport networks was attempted by building the networks using the node-link topology. However, this approach made editing and verification of the data difficult and introduced data redundancy, as route networks had to be digitised "on top of each other", i.e., they had duplicate geometry where several links in the model represented the same physical link (Figure 9.3a).

Later, turntables were introduced in GIS. Turntables made it possible to describe turns and turn restrictions at intersections modelled as nodes. Turntables can also be used to represent changes between routes at stops in public transport systems (Figure 9.3b). However, the problem of redundant data at the link level still prevails using this approach. Furthermore, it is necessary to implement various editing tools to ensure the consistency of the data. Later dynamic segmentation was introduced.

Dynamic segmentation is the representation of points and lines (events) along a sequence of existing links, potentially useful when describing public transport networks (Nielsen et al., 1998b). The method was used in the projects ALTRANS (Thorlacius,

Figure 9.3: Common workarounds used to handle public networks in GIS
The experiences recounted above lead to the conclusion, that so far, it has been difficult to establish and maintain models of multi-modal transport networks in GIS. It has also proven difficult to develop even quite simple topological models with the necessary degree of generality. An aspect of this problem is that data models of multi-modal networks often are impossible to describe using existing GIS elements exclusively. Therefore, topological elements often have to be described outside of the GIS. The GIS functionalities to ensure coherence of stored data thereby only cover some of the network connectivity. Overall such data models can be described as 'non-intelligent', since they cannot prevent the existence of inconsistent data.

In parallel with the development of topological models in GIS, transport-modelling packages have been added GIS-like functionalities in order to ease the management of geographic data. However, such software often use proprietary data formats, meaning that it is difficult to use them together with other data formats and external calculation models. This makes it difficult for users to add functionality to the packages, e.g., to add new algorithms or to adjust existing ones. Finally, there is no easy method to synchronise data between applications that handle different aspects of a modelling project (e.g., traffic assignment models and rail simulation models).

Unlike GIS, transport-modelling packages have sought to add the topological models necessary to handle the network data, but not in a general form. Often the models are tightly tied to the algorithms in the package. In addition, tools for editing and visualising data are often inferior to those of a GIS. In some packages, however, the data model may be described as being 'intelligent', as the software has a fair amount of support for ensuring consistency of the data, e.g., the handling of public transport routes.

Attempts have been made to bridge the gap between GIS and transport modelling packages. The EU project BRIDGES developed a conceptual data model describing public transport networks – among other things. This model formed the basis for a formal exchange format, Generalised Transport Format (GTF) to facilitate transfer of data between applications. The work is continued in the research project SPOTLIGHT also funded by EU (Nielsen et al., 2001).

In the ALTRANS project (Thorlacius, 1998), a GIS-based model for public transport networks was implemented. The model included the ability to import timetable data from the different formats used by Danish public transport operators. This reduced the workload establishing the data. However, ALTRANS as a model did have some drawbacks: The
calculation algorithms were quite slow as they were based on the network algorithms implemented in the underlying GIS – in this case ArcInfo 7. In addition, because of its focus, the ALTRANS data model was not designed to ease editing and maintenance of the data.

Because of the ease with which public network data could be established, ALTRANS was however chosen as the data model foundation of the Copenhagen Ringsted Railway Model (Nielsen et al., 2001). The model was adjusted to take account of rail-specific details. Calculations were handled by external applications to optimise speed. Data were exported from the GIS-based model to the calculation programs through an exchange format implemented in a database (Figure 9.4 from the Copenhagen Ringsted Model Nielsen et al., 2001). As can be seen, this model is more extensive than the basic link-node topology.

Nielsen and Frederiksen (2004) describe a more recent ArcGIS-based model, which continue the development outlined above. This has – among other things – formed the data model behind the schedule-based model for Copenhagen described in Nielsen and Frederiksen (2007).

9.1.2 Route choice
The basic premise in most assignment procedures is the assumption of a rational traveller, i.e., one choosing the route that offers the least perceived individual costs. A number of factors are thought to influence the choice of route when driving between two points, like journey time, distance, monetary costs (fuel and others), congestion, type of manoeuvres required, type of road, scenery, signposting, road works, reliability of travel time and habit (Bovy and Stern,
Including all these elements in assignment models is a difficult task. Therefore, approximations are inevitable.

### 9.1.2.1 Cost function

Most route choice models are based on some concept of generalised cost (GC). It is usually the weighted sum of journey time and journey cost, where both aspects might have subcategories. Journey time could be split in access/egress time and in-vehicle time, whereas journey cost could be split into distance dependent costs, like gas, and tolls. In the generalised cost of car assignment, it is important to allow for vehicle occupancy, where the cost of passengers might be weighted differently than the cost of drivers.

A simple car GC is

\[
GC_{\text{car}} = \beta_d \cdot d / (\text{occ}) + \beta_{cp} \cdot c / (\text{occ}) + \beta_{\text{free}} \cdot t_{\text{free}} + \beta_{\text{con}} \cdot t_{\text{con}},
\]  

where \( d \) is distance, \( c \) out-of-pocket cost, \( t \) travel times, and \( \text{occ} \) car occupancy.

In the deterministic case an individual simply chooses the route with the lowest GC. In the probabilistic case the framework of discrete choice models and RUM is easily adopted, see chapter 4. The systematic part of utility is simply \(-GC\). The choice between different routes is described by utilities

\[
U_i = -GC_i + \varepsilon_i,
\]

where \( \varepsilon_i \) follows a specified distribution.

### 9.1.2.2 Correlation of alternative routes

Beside the specification of GC and \( \varepsilon_i \), the route choice demands attention on choice set generation and correlation of alternatives. The correlation of alternatives is very clear in route choice since different alternatives share common links. The problem is that it is difficult to capture this through the systematic part of utility therefore advanced models assume some kind of correlation between the random errors in the utility. Different models have emerged, e.g., path-size logit, logit with commonality factors, network GEV (see, e.g., Frejinger and Bierlaire, 2006, for references) and Probit models (Sheffi, 1985). Of these, we will describe the path-size logit and the probit model.

Theoretically, use of nested logit models allowing correlation between some specific alternatives could also relax the assumption of independence. However, in route choice models the number of alternatives is in practice so large that this approach at the moment is unsuitable.

In order to account for overlap in a route choice-modelling context, Ben-Akiva and Bierlaire (1999) introduces a path-size factor. This path-size factor is an approximation of the amount of overlap of an alternative with all other alternatives in the choice set. It is entered directly into the utility.
where $\varepsilon_i$ are independently Gumbel distributed and

$$PS_i = \sum_{\text{rel}^{L_i}} \frac{1}{\sum_{j\in\text{c}_a} \delta_{ij}}. \tag{9.11}$$

The intuition behind the path-size logit is that if alternative $i$ partly overlaps with other alternatives, the path-size $PS_i$ is smaller than one, and thus the disutility of the alternative increases while its relative attractiveness decreases. Consequently, the probabilities of the unique alternatives increase and the probabilities of the non-unique alternatives decrease. The approach is similar to a NL model.

Daganzo and Sheffi (1977) using probit-based models have suggested a better solution to the problem in networks with overlapping routes. Under the assumption that:

(a) Non-overlapping links are perceived independently,
(b) Links with equal mean travel resistances have the same distribution of perceived resistances,
(c) The perceived travel resistances, $c_{a(\varepsilon)}$, are normally distributed with a mean equal to the travel resistance and with a variance proportional to the resistance:

$$c_{a(\varepsilon)} \in \Phi(c_a, \varepsilon \cdot c_a) \tag{9.12}$$

Where $\Phi$ symbolises the family of normal distributions, $c_a$ is the deterministic travel resistance for link $a$ and $\varepsilon$ is the error term.

They showed, that the probability of using a certain link or route can be described by a Multinomial Normal distribution resulting in the Probit model. Sheffi and Powell (1981) presented an operational solution algorithm in which the road users' perceived travel resistances were simulated. The probit model is a special case of stochastic user equilibrium (SUE) models.

Results on SUE are deduced from an assumption that travel costs are normally distributed. The normal distribution is reproductive in both parameters and hereby both in mean and variance. This property secures – in theory – that SUE is independent of the segmentation of the links in the traffic network. However, the distribution is – in practice - not totally fit to describe the distribution of perceived costs, as negative draws must be truncated. The possibility of truncation is highest at links with low travel resistances, as the variance is calculated as the error term multiplied by the mean in order to secure additive link costs. The gamma distribution seems a better choice, since it is reproductive and non-negative. Tests by Nielsen (1997) on full-scale networks have confirmed this.

### 9.1.2.3 Random coefficient models

The random coefficient models builds on the same idea as mixed logit, where preferences are distributed in the population. Differences in preferences (taste-heterogeneities) can hereby be described.
As a bi-product, the model induces correlation between alternatives, but without direct connection to the network. The main motivation is that differences between user preferences within a group need to be considered. Nielsen (1996) presents a heuristic modification of the probit model in which two types of stochastic components occur - the first considers road users' perception of the traffic network at link level as in the traditional probit and the second considers differences within the road users' utility functions:

\[ U_i = (\beta_i + \xi_t) t_i + (\beta_c + \xi_c) c_i + \varepsilon_a + \varepsilon_i, \]  

(9.13)

where \( \beta \) are coefficients that multiply time and cost. The \( \xi \) represents systematic variation of the coefficients (i.e., \( \xi_t \)-time and \( \xi_c \)-cost are error components). The arc components, \( \varepsilon_a \), represent random variations at the arc level.

### 9.1.2.4 Choice set generation

The second big problem in probabilistic route choice is the choice set generation. In most data sets, only the chosen alternative is observed and it is costly to ask individuals to describe choice sets. In addition, this would probably induce bias.

An overview of ways to generate choice sets is given in Bovy (2007). He defines the choice set as the collection of route options available to the traveller. A first important thing to note is that the choice set might differ between the modellers and the travellers' point-of-view. A second thing is that the generation and choice can be seen as either a sequential two-step procedure or a simultaneous decision. In general, the choice set should include all attractive routes, i.e., it is more important to have all possible alternatives in the choice set at the cost of including some unrealistic ones. Four approaches described are probabilistic IAP, constrained enumeration, deterministic shortest path and stochastic shortest path. Based on the review the constraint enumeration method is recommended. A recent overview of choice set generation methods is given in the Ph.D. thesis by Fiorenzo-Catalano (2007).

### 9.1.3 Assignment algorithms

When the route choice mechanism and input is specified, it is necessary to have an algorithm to assign traffic onto the network. The basic ingredient in all assignment algorithms is some kind of shortest path algorithm that searches for feasible paths between two zones and find the shortest.

Using a shortest path algorithm the simplest assignment algorithm assigns all traffic to the shortest path.⁸ This is known as all-or-nothing assignment. In this way, a shortest path algorithm is the simplest assignment algorithm. In many cases, it is too simple but in case of appropriate segmentation, it might yield a reasonable approximation at a low cost.

A more general procedure useful for algorithms that are more complicated is the method of successive averages (MSA). It assumes a set of initial flows, \( f^0 \). Let \( k=0, f_{UC}(c) \) be a assignment of flows (e.g., all-or-nothing) depending on generalised cost, \( c \), where cost is a function of flow \( c(f) \). A sketch of an iteration is seen below

---

⁸ What is “shortest” depend on the generalized cost.
\[ k = k + 1; \]
\[ c_k = c(f_k^{-1}); \]
\[ f_{UC}^k = f_{UC}(c_k); \]
\[ f_k = f_k^{-1} + \frac{1}{k}(f_{UC}^k - f_k^{-1}). \]

The MSA algorithm is very robust but can have slow convergence. A faster solution algorithm is the algorithm by Frank and Wolfe (1956).

One of the important aspects of a transport model is to achieve a stable result, that is, results which do not change significantly with further calculation. Such stability is very important when using the model to make evaluations of schemes and policies. However, it should be noted that traffic flow is not necessarily an intrinsically stable phenomenon. The tendency to instability grows in real life, and in modelling, as congestion increases. That is, it may not be possible to measure a consistent set of routes in a study area. This is especially the case when there are two or more 'parallel' routing choices for important travel corridors.

Another important aspect is that the solution is unique, i.e. if the model is run twice (e.g., with different seed values for generating random numbers), then the solution should be the same.

And finally it is important that the solution is consistent with the assumptions used, e.g., if the approach aims at a Wardrop equilibrium solution, then the algorithm must secure this.

The MSA algorithm and improvements (such as Frank-Wolfe) secures the above aspect. It has been shown, that other often used algorithms, particularly incremental loading, iterative assignment procedures, and weighting methods that does not follow weighting schemes consistent with MSA (or modifications hereof), do not secure a solution that fulfil all aspects above.

### 9.1.4 Assignment models

When the traffic on a given road segment increases, the road users’ velocity drops until the queue situation, where the traffic flow as well as the velocities are unsteady and often very small. One of the main divisions between assignment models is, whether they consider this correlation (Capacity restraint models) or not (non-capacity restraint models).

<table>
<thead>
<tr>
<th>Capacity restraint</th>
<th>Stochastic effects</th>
<th>Yes</th>
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<tr>
<td>No</td>
<td>No</td>
<td>All-or-nothing</td>
</tr>
<tr>
<td>Yes</td>
<td>Heuristic models</td>
<td>Analytical models for user equilibrium (UE)</td>
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Table 9.2: Classification Scheme of Assignment models
Another main division is, whether the models consider that the road users for unknown reasons are using different routes between two given locations (stochastic models) or not (deterministic models). Table 9.2 below gives an overview of the four main types of assignment models.

The models not including congestion can simply be run in one iteration. In the case of congested models, the concepts of user equilibrium and system equilibrium have to be introduced.

Wardrop’s equilibrium stated by Wardrop (1952) includes two principles:

1) Under equilibrium conditions, traffic arranges itself in congested networks such that routes between an OD pair have equal and minimum costs while all unused routes have greater or equal costs (user optimum).

2) Under social equilibrium conditions, traffic should be arranged in congested networks in such a way that average (or total) travel costs is minimised (system optimum).

In order to take account of the congestion effect, the assignment needs an iterative procedure like the Method of Successive Averages (MSA). The overall traffic demand is split and assigned gradually, such that the link speeds are adjusted according to the new traffic loads after each step.

Next, we will describe the four categories in more depth.

### 9.1.4.1 All-or-nothing

The simplest route choice model is the all-or-nothing model. Its main principle is:

*The individual traveller minimises the deterministic generalised cost*

The all-or-nothing model has some limitations including implicit assumptions:

1) The traffic has no delays.

2) The travellers have full knowledge of the network.

3) All travellers have common preferences.

In pseudo notation, the model is seen below.\(^9\)

\[ T_{ij,r} = \max_k \left[ U_R = - \sum_{a \in R} c_a \right], \]  

(9.15)

Where \( T \) is traffic from \( i \) to \( j \) following arc \( a \) along route \( r \). \( R \) is the route, \( c_a \) the generalised cost of arc \( a \) and \( U \) the utility of each route.

\(^9\) The notation describes the state the model fulfils. It is not the correct formulation of the model as a mathematical program.
In a more compact notation, this is: \( U_a = -c_a \). \hfill (9.16)

### 9.1.4.2 Capacity dependent models

The simplest generalisation of the all-or-nothing model is to include capacity. This build on Wardrop’s first principle.

In the notation from above the model can be formulated as (with \( c = t \)):

\[
T_{ij} = \max_{r} \left[ U = -\sum_{a \in R} t_a \right]
\]

\[\text{u.c. } t_a = f(T_a, t_{a(0)})\]

Or more compact:

\[
U_a = -t_a
\]

\[\text{u.c. } t_a = f(T_a, t_{a(0)})\]

For a more thorough discussion of the model as a mathematical program the reader is referred to Sheffi (1985). The most common algorithm is MSA.

### 9.1.4.3 System optimal solution

When performing system optimal assignment, it is necessary to compute the corresponding marginal cost function. For a given volume-delay function \( t(F) \), the corresponding marginal cost function is defined as:

\[
m(T) = t(F) + F \cdot t'(F)
\]

\hfill (9.19)

The marginal cost includes in addition to the cost perceived by the traveller, \( t(F) \), also the increase in cost \( t'(F) \) his/her travelling causes all other \( F \) travellers on the same link. For the BPR function written in time;

\[
t(F) = t_0 \left( 1 + \alpha \left( \frac{F}{F_{\text{cap}}} \right)^\beta \right)
\]

\hfill (9.20)

the marginal cost is simply...
9.1.4.4 Stochastic models

Stochastic models assume in their simplest form that there is some kind of random variation between the utility functions of the travellers or their knowledge of the network:

The individual traveller minimises her perceived (stochastic) generalised cost

One advantage of stochastic models is that they divide traffic more evenly between routes with similar GC. The model resembles the all-or-nothing formulation except for an additional stochastic part \(\varepsilon_a\):

\[
T_{ij\alpha\tau} = \max_R \left[ U = - \sum_{a \in R} \left( t_{a(0)} + \varepsilon_a \right) \right] 
\]

(9.22)

Or more compact:

\[
U_a = -(t_a + \varepsilon_a) 
\]

(9.23)

Dial (1971) formulated the model as a mathematical program. His formulation was a logit model. The fact that logit has some severe independence assumptions has lead to generalisation like path-size logit, c-logit and probit-based assignment, see Section 9.1.2 on route choice models.

9.1.4.5 Stochastic models with capacity

The final model type combines the stochastic model with the different ways to include capacity on the network. The basic assumption is therefore:

The individual traveller minimises her perceived (stochastic) generalised cost such that routes between an OD pair have equal and minimum perceived costs while all unused routes have greater or equal costs.

The equilibrium of this model type is known as stochastic user equilibrium (SUE). In pseudo notation we have:

\[
T_{ij\alpha\tau} = \max_R \left[ U = - \sum_{a \in R} \left( t_a + \varepsilon_a \right) \right] 
\]

(9.25)

\[
\text{u.c. } t_a = f(T_a, t_{a(0)}) 
\]
Daganzo and Sheffi (1977) formulated the SUE principle and mathematical program. Sheffi and Powell (1982) found an operational solution algorithm using MSA.

As a recap, each assignment method has several steps, which must be treated in turn. Their basis functions are:

- To identify a set of routes which might be considered attractive to drivers;
- To assign suitable proportions of the trip matrix to these routes; this results in flows on the links in the network;
- To search for convergence; many techniques follow an iterative pattern of successive approximation to an ideal solution, e.g., Wardrop’s equilibrium; convergence to this solution must be monitored to decide when to stop the iterative process.

9.1.5 Extensions and software

The assignment models described above have many extensions. In the following, we will shortly describe some of these.

9.1.5.1 Multi-vehicle classes

The assignments model above were only described for one class of vehicles. The split into multi-class models can be very important if different units use the same road space. The fact that trucks and cars have very different speed-flow curves and travel costs could make this important. A formulation of a multi-user class model is given in Nielsen (1998a).

9.1.5.2 Segmentation

The question of different segments is very central given that they often share the same network. The segmentation could be done along many dimensions, e.g., time-of-day, purpose, distance, or income.

The segmentation by purpose is supported by the fact that work trip travellers often have a higher knowledge of the network. Furthermore, business travellers have a significant higher VoT. Such segmentation can be described in a multi-class assignment model, adding more classes than vehicle types only.

In most demand model, there is some kind of segmentation. If this is important in the demand-modelling context, it is important to allow for multi-user class in the assignment as well. Otherwise, the details of the demand model will be lost in the assignment procedure.
A special segmentation is the segmentation by time of day. Since much infrastructure only suffer from capacity problems at specific times of the day, it is very central to policy issues in this respect.

Some years ago, it was common to assign only one-hour peak-matrices. A common time period in Northern Europe was from 7.30 until 8.30 hour am and/or 16.30 until 17.30 hour pm. However, nowadays peaks are becoming wider because of congestion. A standard approach in some countries is therefore to perform an assignment for the two-hour peak period (7 until 9 am and/or 16 until 17 hour pm), whilst other models (see, e.g., Vuk and Hansen, 2006, about the OTM model) model peak and shoulders separately. The recent OTM model (Nielsen et al., 2006) models the day segmented into 7 time periods.

Secondly, due to the focus on accessibility issues, the transport model is usually only made for working days. To carry out an assignment for an average working day (24 hour) situation it is best to run assignments for the peak moments (two-hour morning peak, two-hour afternoon peak) and the off-peak period and sum these assignments for the 24-hour situation.

A new development is that for all kind of environmental studies (air quality, pollution, noise) there is a need for travel volumes based on an average weekday. Therefore, it is necessary to assign weekday matrices; in most practice, the workday assignment is multiplied by a factor. This factor can be deduced from traffic counts for both periods.

9.1.5.3 Dynamic assignment

The static assignment model does not capture the time-varying nature of traffic; it assumes that traffic has reached the steady state. In addition, static traffic assignment assumes a uniform spatial distribution of traffic. For instance, in a larger network where a trip could take longer than an hour to complete, a static traffic assignment of hourly travel demand analysis will misrepresent this real situation. The assumptions of static assignment models are accordingly not suitable for some transportation systems (e.g., congested urban road networks at rush time). Many researchers (e.g., Ben-Akiva, 1985, and Friesz, 1985) recognise these unrealistic assumptions.

In general, dynamic traffic assignment (DTA) models differ from their static counterpart in view of that they reflect traffic variations over time. This means that travel times at link levels varies dynamically over time, but that route choice varies as well, e.g., a car user leaving a suburb at 6.50 takes into account the larger congestion level in the city centre when he/she arrives at 7.20. Dependent on the sophistication, dynamic models may incorporate queues and spillback on traffic from bottlenecks.

Since Merchant and Nemhauser (1978a, 1978b) formulated a dynamic system-optimal (DSO) route choice model, DTA models have received intensive attentions from researchers and practitioners. Over the past twenty years, there have been more than thirty models under development (Algers et al., 1997).
DTA can be realised with a flow-based analytical approach or a vehicle-based simulation approach. Depending on methodology employed, the analytical DTA models can be further classified into mathematical programming, optimal control, and variational inequality (VI) models. As in the static case, most formulations tend to focus on the user equilibrium (UE) and system optimal (SO) objectives.

For applying a dynamic assignment instead of a static assignment, some extra information is needed. For example, for a macroscopic dynamic assignment the following attributes have to be added at each network link:

- Number of lanes;
- Free-speed;
- Saturation flow;
- Speed at capacity.

Regional networks are normally too big for applying dynamic assignments; therefore, a sub-network must be made for the area of study and accordingly a sub-matrix.

Because the time component is an extra dimension in dynamic assignment, one has to split up the static OD matrix (for example a two-hour peak matrix) in parts of, e.g., 5 minutes. Therefore, a profile is needed because the traffic is not uniform distributed during the two-hour period. This profile can be obtained from count information. Jia (2007) provides a literature review of DTA models.

### 9.1.5.4 Intersection delays

In metropolitan and urban model it could play a big role that driving includes many turn movements. In applications, the delays are included in the model through calibration, which spreads out the delays to the whole route. This might be insufficient in some planning contexts where the turning movements are significant.

The model described in Nielsen et al. (1998b) includes the following two types of delays. In intersections with no signal:

\[
Total \ delay = deceleration + delay \ from \ queuing + \ waiting \ for \ turn \ opportunity + Acceleration
\]  
(9.27)

And in regulated intersections:

\[
Total \ delay = deceleration + delay \ from \ queuing \ 1 + wait \ for \ green \ light + delay \ from 
queuing \ 2 + waiting \ for \ turn \ opportunity + acceleration
\]  
(9.28)

Another reference on intersection delays is Frederiksen and Simonsen (1997).
9.1.5.5 Micro simulation - road

Micro simulation models simulate detailed driving behavior in road networks. Such models include all details concerning lanes, turns, signals, etc. Whilst some packages do not incorporate rigid route choice formulas, others such as VISSIM make it possible to use utility functions and equilibrium schemes. The SMARTEST\(^{10}\) homepage at University of Leeds include a thorough review of micro-simulation models (methods and software).

9.1.5.6 Micro simulation - rail

Simulation models are quite often used in rail capacity analyses. These models simulates the movements of trains, in detailed networks including descriptions of tracks, switches, signals, interlocking systems, etc. Two often used software packages are RAILSYS\(^{11}\) and OpenTrack\(^{12}\). Although it is fairly seldom that rail simulation models are integrated with passenger simulation model, some examples are Nielsen et al. (2001) and Nielsen and Landex (2006).

9.1.5.7 Meso simulation

Over the last decade, traffic simulation models, often called micro-simulation models, have become an increasingly popular tool for modelling urban traffic. These models provide a two- or three-dimensional animation of the movement of each vehicle in the network, making it relatively easy for the analyst to understand the underlying mechanisms (causes) of congestion at each bottleneck in the network. What is generally not very easy to evaluate is the quality or nature of the routing logic used to determine which path each driver uses to attain his or her desired destination. Moreover, routing models that explicitly represent the individual decisions of drivers in the presence of varying levels of information (referred to as descriptive routing models) are not generally well suited to the problem of finding the optimal route-choices, regardless of whether the aim is to obtain user-optimal or system optimal conditions. Dynamic models on the other hand may describe some time-variations, although queues are described rather roughly.

The meso-simulation models tries to bridge these two approaches, i.e., running at a more aggregated level than most micro-simulation models, yet describing some queue phenomena and flow-density relationship using meso-simulation. The recent Dymameq\(^{13}\) model is an example of such an approach.

9.1.5.8 Software

As with all aspects of transport modelling, the choice of software is between specially developed software and commercial software. The first type demands expertise and time resources while the second demands money resources and might limit the flexibility of the

\(^{10}\) http://www.its.leeds.ac.uk/projects/smartest/append3d.html
\(^{11}\) http://www.ive.uni-hannover.de/software/railsys/index_en.shtml
\(^{12}\) http://www.opentrack.ch/
assignment model. Therefore, the choice is highly context-dependent. A first consideration should be if commercial software can fulfil the objectives given some budget. Some of the more widely used software packages in Europe according to MDIR are EMME\textsuperscript{14}, TRIPS (now part of CUBE), VIPS\textsuperscript{15}, Traffic Analyst\textsuperscript{16}, VISUM\textsuperscript{17}, TransCAD\textsuperscript{18}, OMNITRANS\textsuperscript{19}, SATURN\textsuperscript{20} and CUBE\textsuperscript{21}. A description of the first tree packages and a comparison is given in Brems (2001). One conclusion in her thesis is that the programs show significant differences in output for some test cases. Hence caution should is warranted when using commercial software.

9.2 Estimation, calibration and validation

In assignment modelling, the division between estimation, calibration and validation is not that clear. In large-scale models, one can say that estimation is used for input parameters such as VoT (Value of Travel Time Savings), which is transferred from other studies. The assignment model is then calibrated and validated in an iterative procedure.

9.2.1 Estimation methods

The main estimation task concerning assignment models is the estimation of the route choice model. This could be both the specification of the generalised cost function or the parameters (e.g., speed-flow parameters), only. Therefore, the estimation builds on the framework for estimation of discrete choice models presented in Chapter 4. The classic way to estimate these would be to transfer values from route choice RP data. The crucial part of this is the quality of data. One specific problem is the description of non-chosen alternatives. A second problem with route choice data, there is a potentially large choice set. New methods based on GPS and/or mobile phones might in the future remove some of these difficulties.

Specific issues, which have to be dealt with in the estimation, is the choice set generation and the issue of large choice sets. The generation will generally follow methods described in Bovy (2007). The issue of large choice sets is described in Ben-Akiva and Lerman (1985).

Estimation of route choice on Stated Preference (SP) data can be used but the question of transferability has to be considered. In general, this can be used to infer parameters, e.g., willingness to pay. Whereas the full route choice model need RP to be estimated or calibrated.

9.2.2 Calibration issues

When the model parameters have been estimated the process of calibration begins. Model calibration adjusts parameter values until the predicted travel matches the observed travel within the region for the base year. The tests on whether the base year is matched are both

\textsuperscript{14} http://www.inro.ca/en/products/emme/index.php
\textsuperscript{15} http://www.ptv-scandinavia.se/vips/introduction/intro2.html
\textsuperscript{16} http://www.rapidis.com/trafficanalyst.htm
\textsuperscript{17} http://www.english.ptv.de/cgi-bin/traffic/traf_visum.pl
\textsuperscript{18} http://www.caliper.com/tcovu.htm
\textsuperscript{19} http://www.omnitrans-international.com/
\textsuperscript{20} http://www.its.leeds.ac.uk/facilities/icity/facilities/saturn.htm
\textsuperscript{21} http://www.citilabs.com/cube/
statistical and visual. Inspection of total flows or filters can be useful. For purposes of forecasting it is assumed that these parameters will remain constant over time.

One of the often used methods for calibration is to move zone-centroids within zones to obtain a better fit with flows, to adjust lengths and travel times at zonal connectors and to add zonal connectors. It is generally recommended, that such adjustments are made transparent, i.e. instead of changing length and time attributes then multiplying these with constants. More drastically, one can adjust zones or even add zones to the model.

Another calibration issue is that some SP surveys may overlook causal relationships that become clear when the results are compared to counts. As an example, the analyst may assume that fast and slow busses have the same value of time, why this issue was not addressed in the SP. Then when the modelling results are shown, fast busses have systematically too few passengers and slow busses too many. The calibration phase may then adjust the time coefficients (or other variables such as hidden waiting time).

A third issue is that most SP survey designs are configured in a way that nonlinearities cannot be estimated. This may be a too coarse assumption if there is a wide distribution of, e.g., traveling times in the network. The issue may be crucial with respect to access modes to public transport (Mabit and Nielsen, 2006) or in models that cover entire regions. As an example regional train may have higher value of time due to longer trip lengths rather than due to comfort related issues.

9.2.3 Validation
Model validation tests the ability of the model to predict future behavior. Validation requires comparing the model predictions with information other than that used in estimating the model forecast. Validation is typically an iterative process linked to calibration. If the analyst finds that the model output and the independent data are in acceptable agreement, the model can be considered validated.22

There are normally two types of validation checks - reasonableness checks and sensitivity checks. Reasonableness checks are tests that include the comparison of rates, checking of the total flows. The analyst evaluates the models in terms of acceptable levels of error and consistency of model results with the assumptions used in generating the results.

Besides looking at aggregated numbers such as comparing model results with traffic counts, it can be useful to look at more disaggregated results, such at bundles of routes between a certain pair of zones, sheaves of routes passing a certain road segments, starts of routes leaving a zone, etc.

Sensitivity checks are tests that check the responses to transportation system change, socioeconomic change, or political changes. Sensitivity often is expressed as the elasticity of a variable. For example, one might examine this impact on travel demand if parking or toll fees are doubled.

22 This section is inspired by http://ctr.utk.edu/TNMUG/misc/valid.pdf
In practical application the meanings of calibration and validation have changed over the years. This is especially true in areas where funding limitations preclude the conduct of travel surveys. In many of these locations the processes of calibration and validation have become a single exercise. Without current OD studies, many of the models are calibrated by using default values derived from other studies and transferred to the local environment. In this process, calibration and validation are merged since an independent database is not available for validation. In order to develop a good match between model link volumes and ground counts, model parameters are modified to provide “reasonable” agreements.

The ultimate test of a travel demand model set is its ability to accurately predict traffic volumes on the transportation system. Therefore, in many areas traffic counts are the primary data parameter used for model validation. A number of checks are used to compare the model’s simulated link values with the traffic counts. In any accuracy check it must be recognised that there are errors associated with the ground counts. These errors are due to equipment malfunction, the inappropriate use of daily and seasonal factors to estimate Annual Average Daily Totals (AADT), and the absence of good classification data to correct axle counts to vehicles. Likewise, while validation involves the results from the assignment phase of the four-step travel demand process, the errors can be attributed to all phases in the modelling process. Errors from previous steps may either compensate or be additive.

Comparing assignment with counts
After assigning a trip matrix of the base year, the quality of the assignment can be checked by comparing it with counts. It is impossible that in the assignment all the link flows will be equal to the measured values, because for example the counts do not have all the same reliability. Therefore, a standard has to be defined to judge the assignment. An example of judging assignments is shown in Table 9.3.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Variabele</th>
<th>Count range</th>
<th>Day period</th>
<th>Peak hour(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>assignment</td>
<td>screenline</td>
<td>2.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td></td>
<td>&lt; 1,000 cars/day</td>
<td>15%</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>tot 5,000 cars/day</td>
<td>10%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>tot 10,000 cars/day</td>
<td>5%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 10,000 cars/day</td>
<td>2.5%</td>
<td>2.5%</td>
<td></td>
</tr>
<tr>
<td>Public</td>
<td>transport assignment</td>
<td>screenline</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>&lt; 1,000 passengers/day</td>
<td>25%</td>
<td>35%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 1,000 passengers/day</td>
<td>15%</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>boarding/aligning</td>
<td>&lt; 100 passengers/day</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 100 passengers/day</td>
<td>10%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 9.3: Assignment validation

Overall criteria:
1. Regarding the checking at screen lines, at 90% of the screen lines the named deviation has to be fulfilled. So for example, for public transport the table yields that at 90% of the screen lines the deviation between link flow and count is less than 5%.
2. Secondly, for all screen lines (i.e., 100%) the maximum deviation is 1.5 times the named standard. So for example, for public transport it yields that all screen lines should have a deviation less than 7.5% compared to the counts.

Another criterion is the so-called T-value. The T-value is commonly used for peak models and takes into account the percentual deviation but also the absolute value of the count. For example, a deviation of 20% is not a problem if the count value is 500 cars, but it is a problem for a count value of 5,000 cars.

The T-value is defined by:

\[ T = \ln\left(\frac{(X_m - X_c)^2}{X_c}\right) \]  

where

- \( T \) = deviation
- \( X_c \) = count value
- \( X_m \) = model value

For a **car assignment** the norms are:

- if \( T < 3.5 \): no relevant deviation;
- if \( 3.5 < T < 4.5 \): in between no relevant deviation and relevant deviation;
- if \( T > 4.5 \): relevant deviation.

At least 80% of the counts should have a T-value < 3.5 and 95% < 4.5.

For a **public transport assignment** the norms are:

- if \( T < 4.0 \): no relevant deviation;
- if \( 4.0 < T < 5.5 \): in between no relevant deviation and relevant deviation;
- if \( T > 5.5 \): relevant deviation.

At least 80% of the counts should have a T-value < 4.5 and 95% < 5.5.

Apart from making tables of comparisons between counts and model values, it can be helpful to make graphical comparisons. Figure 9.5 shows an example.
9.3 Issues related to focus

9.3.1 Regional economics
When the need for transport infrastructure has to be forecasted, economic models are necessary to analyse the underlying economic relations determining transport demand. Furthermore, an economic model is vital for incorporating the feedbacks from the economy into transport forecasting models designed for evaluating policy scenarios.

If certain policies such as infrastructure investment or pricing affect the transport cost, this induces income, production and trade adjustment processes, which in turn affect the transport demand.

The transport system affects the economy because trade of goods between regions is costly. There are three kinds of resources required:

(1) Information and service costs, e.g., business passenger travel containing time costs or out-of-pocket costs.

(2) Transportation costs (freight costs), including costs for logistics.

(3) Transport time, since the time use require resources (salary, depreciation, etc).
The transportation system determines the costs of trade and therefore the relative prices of goods. On the supply side, transport initiatives influence production costs, since imported goods are used as inputs in regional production. On the demand side, a change in relative prices between imports and locally produced goods also leads to a shift of relative demand.

9.3.2 Strategic
In a strategic model, the assignment model is often less detailed than in tactical models whereas the focus is on the interactions between assignment, the other parts of the traffic model, and maybe land use or economic models. It is therefore central to find the aspects where the assignment needs to be precise, e.g., it could be that congestion is important then a model with congestion without stochastic might be sufficient.

9.3.3 Tactical
This is typical the focus of most standard assignment modelling software. At this level, there is a trade-off between detail of the assignment and interactions with other levels of the traffic model.

9.3.4 Operational
Operational models, includes network effects at a more detailed level than the usual tactical models.

In road assignment models, this may be intersection delays (refer to section 9.1.5.4), queues and spillback, and dynamic effects (refer to section 9.1.5.3). Sometimes operational models cover a sub-network of a larger tactical model. It is however difficult to secure consistent links between model levels, as this is not easy to do with most standard software (although some vendors have links between software at tactical and operational level, such as CUBE\textsuperscript{23}, VISSUM/VISSIM\textsuperscript{24} and TransCAD/TransModeler\textsuperscript{25}).

In rail assignment, the link to the operational level may describe passenger delays or links to rail simulation models (Nielsen et al., 2007).

9.3.5 Optimisation
Finally, transport assignment models may be linked to optimisation models, which optimise the network given the transport flows. A general introduction is Bertsekas (1998). Another good reference is Van Vuren and Van Vliet (1992).

In road assignment optimisation mainly concern price levels in road charging systems. Although this is a very relevant issue, most research and model examples are run on “toy networks” rather than on the level of detail that is used for policy analyses. In practice, charging levels are often set by running the model with different charge levels, and then choosing between these. The levels at each iteration may be set by interpolating between prior iterations or by calculating the marginal costs of transport.

\textsuperscript{23} http://www.citilabs.com
\textsuperscript{24} http://www.english.ptv.de/cgi-bin/traffic/traf_vision.pl
\textsuperscript{25} http://www.caliper.com/
Timetable optimisation in public transport is another field with a large potential of operational improvements. Little research has been done in this field.

Nielsen et al. (2007a) describe a project where an air transport assignment model is linked to an optimisation model, whereby the air network (leg-structure, timetable and use of types of airplanes) is optimised conditional on the flows.

In most cases, the assignment model is a non-linear, non-continuous, discrete mapping of the travel matrices assigned onto the network that is the outcome of the optimisation. The optimisation models have an object function that is conditional of the output of the assignment model. Typically, this difficult bi-level optimisation problem requires meta-heuristics to be solved and large calculation times. However, there is no doubt that linking transport assignment models to optimisation models possesses large potentials for optimising the actual operation of transport systems.

9.4 Specific modelling areas

9.4.1 Taxation and charging
The following discussion is based on webtag26. All forms of road pricing require the representation of road pricing on the highway network and its inclusion in the formulation of generalised cost. The form of road pricing to be considered will affect the way in which it is represented in modelling. Whilst the form of road pricing has a substantial effect on the way it is represented on the modelled highway network used for assignment, the way it is included in the formulation of generalised cost is common to all. In addition, in most cases, the basic components of generalised cost (time, distance, road price, and other money costs) are skimmed from the network used in assignment and used to construct generalised costs for use in the demand model. Therefore, this section discusses its representation on the modelled highway network for each of the principle forms of road pricing.

Cordon pricing
Cordon pricing is probably the easiest to represent in modelling. Each link in the highway network that crosses the cordon is assigned a price. The price on all links may be the same, or it may vary from link to link. Prices may be represented as applying in one direction only, or in both directions.

Distance pricing
For distance-based pricing, the approach is similar to cordon pricing. Each link to be priced must be identified and assigned a price, in this case depending on the link length. This process may be carried out within the assignment model, or it may be done outside the model - the price for each link is unaffected by the link flow or other model outputs, so both approaches are acceptable. The rate per unit distance may be the same for all links, or it may vary from link to link.

26 http://www.webtag.org.uk
Area licences

Area licences, as implemented in the London Congestion Charging scheme, are more difficult to model, for two reasons. First, one payment allows the vehicle to be used for as many journeys as the driver wishes. This means that the cost per journey or per hour within the zone is difficult to estimate. Second, a payment (possible at a lower rate than for those entering the area) is levied on vehicles based within the priced area if they use the roads, even though they may not cross the cordon. Modelling area licence schemes also depends on the form of the assignment and demand models. The following paragraph outlines an approach that has proved successful, but the precise method adopted will need to be tailored to the model structure that is available.

An area licence scheme can be modelled by a combination of a cordon price applied to trips generated outside the charged area ('non-residents') and a penalty price applied to all trips generated within the charged area ('residents'). To facilitate this, it will usually be necessary to segment the demand and supply models into residents and non-residents. This segmentation is in addition to the segmentation required as part of the core requirement. It is reasonable to assume that most trips are part of a daily 'tour', comprising, as a minimum, an outbound and return trip. Therefore, the price of an area licence should be 'shared' across all the trips in a typical daily tour. Ignoring non-home based trips would lead to a halving of the price to obtain the price per trip. However, an allowance for non-home based trips should be made, where appropriate. The resulting price per trip is suitable for use as an in-bound cordon charge, applicable to non-residents only, for use in the assignment model. Used in this way, it will ensure that alternative routes for through trips are appropriately priced and hence ensure that diversion is correctly modelled. Route choice is not an issue for non-residents entering the licence area, since all cordon crossings will be priced the same. The price per trip will also be suitable for use as a penalty price for residents in the demand model and in appraisal. Costs skimmed from the network for through trips will also be suitable for these purposes. However, it will be important to ensure that, for non-residents entering the licence area, costs skimmed from the network for use in the demand model or for appraisal purposes take account of the price per trip assumed to apply to outbound trips.

Marginal Social Cost (MSC) based pricing

MSC based pricing may not be practical to implement, but it provides a useful benchmark against which to gauge the efficiency of more practical schemes. However, MSC based pricing presents a significantly different challenge for modelling. MSC based prices are related to the flow on a link. Thus, the challenge is to identify the price that is consistent with the flow on each link in the priced network. Prices cannot be estimated outside the model and input, as is the case for other forms of pricing. They must be estimated within the model. The estimation process will require an iterative procedure, iterating between price setting and model responses to the price. An approach that has proved successful assumes that MSC based prices will reflect all the elements of external costs, including the congestion impact of vehicles in delaying other vehicles, as well as the impact on fuel consumption and environmental costs. In some cases, particularly for local pricing schemes, it may only be necessary to consider the congestion element of the external cost. Section 9.1.4.3 described how the cost function in a user equilibrium based assignment easily could be transferred to describe the marginal costs.
Exemptions and other considerations

Exemptions need to be considered against the objective of a scheme, which is to tackle congestion. It is therefore suggested that the starting assumption should be that any vehicle that contributes to congestion should be covered by the scheme. Where exemptions cannot be avoided, their impact on the effectiveness of the scheme must be carefully and thoroughly analysed. Exemptions can take many forms. Some may have a significant effect on the impact of road pricing others may be negligible. Where exemptions are expected to have a significant effect, they should be represented in modelling, to the extent that it is possible to do so. The following paragraph outlines some examples of exemptions that can be represented in modelling relatively easily.

Exemptions (including discounts) applying to specific user groups can be represented by appropriate segmentation of the model. However, this is only likely to be worthwhile if the user group is quite large. Exemptions for small user groups may be excluded from some or all modules of the model. For example, they may be excluded from the variable demand modelling (thus implying a fixed matrix) but added into the matrix to be assigned to the network. Alternatively, they may be preloaded to the network if their routeing is expected to be fixed. Exemptions (or discounts) may apply to certain geographical areas. Again, segmentation will allow a separate pricing structure to be established for the exempt locations. Discounts for those within the boundary of an area licence scheme can be relatively easily dealt with (at least approximately) by adjusting the penalty price to be charged for trips generated within the boundary.

Most road pricing studies will wish to explore prices varying by vehicle type and by time of day. Pricing (or exemption) by vehicle type can be accommodated, provided the assignment model is appropriately segmented. The ability to test pricing by time of day will be limited by the modelling of time-of-day effects. The core requirement is for the morning and evening peak and the interpeak periods to be modelled.

9.4.2 Mode choice

In general, mode choice is included in the demand model and the assignment model is conditional on the mode choices made. Some exceptions from this approach are simple transport models where assignment between similar modes is included in the assignment.

Another group of models are multi-modal assignment models that describe chains of modes. The assignment models may be very advanced in this case. Some cases where mode choice is often included in assignment are:

- Access modes to airports, see Section 9.8.
- Metropolitan urban transport models with use of slow modes or public transport see Section 9.7.
- Modelling of logistic chains, and mode chains in freight transport.
9.5 Road transport

As road assignment models are the main stream of transport assignment, most issues concerning road transport are dealt with within the more general sections of the chapter. It is mainly in more detailed models, where approaches that are more specific are needed, e.g., intersection modelling (Section 9.1.5.4), dynamic assignment (Section 9.1.5.3), meso simulation (Section 9.1.5.7), or micro simulation (Section 9.1.5.5).

9.5.1 Road pricing and fiscal policies

The purpose of road pricing can be understood through Wardrop's two principles. Without road pricing, traffic will settle on a user equilibrium, which from a network point-of-view is inefficient. The system optimum leads to efficient behaviour on the network. Pricing leading to the system optimum is known as first-best pricing. This is a theoretical concept therefore work has been done on second best pricing, see, e.g., Verhoef et al. (1996).

The state-of-the-art approaches to passenger demand modelling in combination with auto and transit assignment models can be applied to analysing road pricing, congestion charging; transit fare reforms, vehicle and fuel taxation, etc. The reservations concerning the use of static assignment models in situations with severe congestion should be considered (see the previous section).

The Stockholm trial on congestion charging (January – July 2006) constitutes a recent example on how state-of-the-art passenger demand modelling and static assignment models can be used to analyse cordon tolls in combination with improved public transit services. The forecasts were made by the SAMPERS regional model system. They turned out to be reliable in terms of vehicle flows but underestimated the travel time gains. A rich set of before-and-after data and modelling applications is available.

The Copenhagen AKTA GPS experiment provided a comprehensive basis for analysing road users’ route choice behaviour in congested networks with charging. Both km.-based and cordon based systems were analysed. Nielsen (2004b) describes the general assignment model, whilst Rich and Nielsen (2007) describe the overall modelling results. A core issue in the assignment modelling was the ability to describe differences in road users values of times and willingness to pay. This was dealt with by using a random coefficient model that included correlation between different time-components.

The assignment of traffic on the road network used a route choice model that was estimated based upon the AKTA data. The demand matrices follow the structure in the OTM model (Jovicic and Hansen, 2003) and describe traffic between a 618 by 618 zone structures onto which elasticities from the demand models were applied. The route choice model was estimated by the following approach (Rich and Nielsen, 2006):

1. The statistical distribution of the car drivers’ Value of Time (VoT) was estimated based on a smaller AKTA sample of 84 car drivers trips (Menegazzo, 2003). Each car had driven between 150 and 1,000 trips. Individual VoT’s could therefore be calculated by averaging over the trips. The model was estimated by comparing all drivers VoT, i.e., the distribution type (lognormally distributed VoT’s), variance (and
derived from this the parameterisation of the distribution), extra value of congestion (also lognormally distributed), and correlation between VoT’s for free driving time and extra time due to congestion.

2. The mean level of VoT’s was then scaled for the different trip purposes following prior surveys Nielsen and Jovicic (1999); i.e., leisure trips (low VoT) and commuting (high VoT). The same types of distributions were assumed for business trips, vans, and trucks, but scaled to mean values from Nielsen et al. (2000). All values were then scaled to 2005 prices. Table 9.4 shows these VoT’s.

3. Calibration of route choices on observed traffic volumes and speed measurements from AKTA and the congestion project (Nielsen and Landex, 2004). The calibration concerned primarily link travel times in the network, speed-flow curve parameters, and adjustments of zonal connectors.

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Free-flow</th>
<th>Congestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Business</td>
<td>20</td>
<td>33</td>
</tr>
<tr>
<td>Leisure / Shopping</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Van/trucks</td>
<td>77</td>
<td>108</td>
</tr>
</tbody>
</table>

Table 9.4: Value-of-time for cars derived from AKTA in Euros/Hour

The applied route choice model generates a stochastic user equilibrium over the trip purposes as described in (Nielsen et al., 2000) but with utility functions for each trip purpose specified as follows;

\[ U = \beta_k \cdot k \cdot l + \beta_c \cdot c + \beta_{\text{road}} \cdot \beta_{\text{free}} \cdot (t_{\text{free}} + \beta_{\text{con}} \cdot t_{\text{con}}) + \epsilon \]  

- \( \beta \) was a coefficient for the usual driving costs such as fuel, oil, and wear and tear. \( \beta \) was assumed to be proportional with the travel length \( l \) with a factor \( k \) (driving cost per km of 0.7 DKK). The present model assumed \( \beta \) to be fixed. \( \beta \) was furthermore fixed to 1 by scaling the model, whereby the function directly occurred in monetary values – the so-called VoT-space.

- \( \beta_c \) was the coefficient for the extra travel cost relative to \( \beta_k \) as due to road charging \( c \). A value larger than 1 of this parameter would imply that road users implicitly or explicitly considered charging worse than normal driving cost. In the model \( \beta_c = 1 \) was assumed, which was partly justified by prior work in Nielsen and Jovicic (1999).

- \( \beta_{\text{free}} \) was the coefficient for the free flow driving time \( t_{\text{free}} \), i.e., the time it would have taken to drive along the route if no congestion had occurred. \( \beta_{\text{free}} \) was assumed to follow a statistical distribution among drivers, which based on AKTA-data was estimated to be lognormally distributed.

- \( \beta_{\text{con}} \) was the extra value of time due to congestion relatively to the value of free flow time \( \beta_{\text{free}} \). This was also estimated on AKTA data and assumed lognormally distributed. \( \beta_{\text{con}} \) was calculated as \( (1 + \ln(\mu, \sigma^2)) \), i.e., \( \log(\beta_{\text{con}} - 1) = \mathcal{N}(\mu, \sigma^2) \). The idea with this was that the product of \( \beta_{\text{free}} \) and \( \beta_{\text{con}} \) also is logarithmic normal distributed. The joint distribution of
VoT is hereby lognormally distributed, but the model is formulated in a way, where correlation could be implemented in the assignment modelling software. The correlations secured that a person with a high VoT of free flow time had an even higher VoT of congestion. Whereas a person with a low free flow VoT also had a low congestion VoT although still higher than the free flow VoT.

- \( \beta_{road} \) was a road type specific correction, which was set to 1 for motorways and could have higher values for smaller roads. This can be considered as a behavioural parameter for "soft" issues such as knowledge of the network, comfort, etc., which cannot be described by travel time alone.

- \( \epsilon \) was an error term scaled to the VoT-space. As the model ran on a network level this was applied for each link, with a variance assumed to proportional with the link length measured in VoT. The model hereby considered overlaps of routes. To avoid truncation of the Normal distribution in a simulated Probit model, a Gamma distribution was used as outlined in Nielsen et al. (2000).

The main advantages of the route choice model – besides superior fit to observations compared to more simple functions – was that it explicitly described differences of car drivers’ willingness to pay for travel savings. This reflects that drivers with high value of time and high willingness to pay are the ones that will get the larger benefits of pricing, whilst drivers who change behaviour have a lower value of time and therefore get at less reduction of utility than an average driver VoT would indicate.

9.5.2 Identifying bottlenecks

Bottlenecks are handled rather superficially in static traffic assignment models. Link-based speed-flow relationships are used to represent all kinds of delays, which are due to high capacity use including, e.g., queuing at intersections. At best, the models project average delays reasonably well. However, it is well known that the state-of-the-art static traffic assignment models are not well suited to represent highly congested situations or situations where a certain bottleneck leads to the building-up and dissolving of queuing effects on many links in the network.

In the case of severe bottlenecks, dynamic traffic assignment and/or micro-simulation approaches should be considered. Such approaches are also needed for investigating the reliability of services provided by a road network. Reducing congestion increases the reliability, which affects the departure time choices in trip-based travel demand modelling. Travel time variability and dynamic travel supply information are also highly relevant in the detailed scheduling approaches of activity-based travel demand modelling. Reviews of travel time uncertainty and departure time choices can be found in Bates et al. (2001) and Noland and Polak (2002).
9.6 Rail transport

Rail transport in the European Union is undergoing structural change derived fundamentally from the liberalisation process that has been undertaken. In this new environment, appropriate tools for strategic planning would be an important aid to the companies involved.

In the railway sector, strategic decisions (as opposed to tactical or operational decisions) can be defined as long-term decisions that involve large investments and have a significant impact on the system configuration. The planning of a rail freight system is complex and requires the use of techniques to assist in the different planning activities, such as long-term demand forecasting; analysis and selection of technological alternatives; assessment of new infrastructure requirements; and definition of the general operation policy.

The design of the most effective rail transport network, in terms of layout and operation policy and according to the estimations of market development is the challenge. As some authors point out, the design of a transport system often is not undertaken as a global, integrated process. It is fragmented. As an example, infrastructure and operational changes are considered separately or local projects are assessed without taking into account the effect on the whole network.

However, perhaps as a consequence of increasing competitive pressure, new methodologies for strategic planning, which include a network model as a tool of analysis, are being developed. The great advantage of a network model is that it facilitates the integrated analysis of the various components of a rail network and their interactions. Network models vary greatly, depending on the type of decision to be assessed or the techniques used to develop the model. With regard to this second factor, network models can be divided into analytical and simulation models. The models proposed most frequently in the literature are analytical and address tactical decisions. However, more detailed timetable-based simulation models for operational issues have been used increasingly during the last 10 years.

9.6.1 Modelling approaches

As mentioned in the introduction, two distinct approaches to public transport modelling are timetable-based versus frequency-based assignment. This is also a choice, which has to be made in most rail models. We discuss this subject in Section 9.7.

Issues related to rail transport are mainly dealt with in the assignment step as separate rail network models or as part of public transit assignment models. Hence, the demand for travel by rail is normally studied in a multi-modal context with competition between rail and other modes. Russo (2001) provides an example of a decision support system used for tactical decision-making by the Italian State Railways. The system relies on a “diachronic” network model with an explicit treatment of time. The demand side simulates the impact of operational service variables (e.g., timetables, travel times, prices) on the choice of service type, run and class. The system permits train loadings to be projected for the different rail services.

Whilst most transit assignment models applied in regional contexts assume high frequencies of operation, such assumptions are less relevant in national contexts with low frequencies of rail operation. Like the Italian system outlined above, the national model of the Swedish
SAMPERS system uses a timetable-based approach for rail and air travel assignment, see Constantin et al. (2001).

A more simplistic approach is used in the English national model, which approximates crowding and route choices with link-specific speed-flow like functions (Faber Maunsell, 2004).

9.6.2 Reliability

Value of Time (VoT) research indicates that delays and travel time variability is perceived worse than expected travel time, i.e. the value of time of delay is higher (Bates et al. 2001 and Noland and Polak, 2002). Considering the focus on rail delay in the public debate in many countries, surprisingly few studies of rail delay value of time have been made. Some further references are Abkowitz (1981a and b), Bates et al. (1997), Benwell and Black (1984) and Polak and Han (1998). The values used in the present article are based on a SP survey and estimates from Nielsen (2000), whilst a more complex model based on the same SP data was estimated in Mabit and Nielsen (2006).

Even though delays have great importance for the valuation of public transport as shown in the VoT research, evaluation and forecasts of punctuality and reliability of railway systems have in practice – if at all – been computed for trains, not for passengers. Furthermore, when passenger delays have been calculated, the underlying models have not explicitly considered how passengers’ react on the delays they experience on-route when they are travelling. Passenger delays differ however from train delays due to the following reasons:

- The number of passengers per train varies. Since train delay is mainly a function of the number of passengers (door interchanges) and capacity utilisation27 (risk delays from one train propagate to other trains), it is likely that trains with more passengers in the rush hours are more likely to be delayed than trains with fewer passengers outside the rush hours. Trains in the intensely used part of the network tend also to have more passengers and be more sensible to delay propagations. Train delay measurements tend accordingly to underestimate the delays that passengers experience.
- If passengers transfer between train lines, the situation is even more complex. If the next train line is reached anyway, then the passengers may only consider the delay of this train line as a problem (except the annoyance factor on the first train line). However, if the connection is loosened, then the delay may be much larger than just the delay of the arriving train (Bates et al., 2001). Some passengers may even get a better connection, if a prior and more convenient train connection is delayed, whereby the passenger can board this and reach the final destination before planned.
- The same track may be served by many train lines. Passengers on short trips may not experience a delay, if they can take another train at the planned time leading to the same destination at the same time as with the planned rail service.

Even though a utility function may have been estimated based on SP data, it is accordingly not trivial how to apply this in a schedule-based route choice model for public rail transport. Nielsen and Frederiksen (2007) describe a passenger route choice model linked to a rail simulation

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27 The train intensity compared to the amount of trains which infrastructure can handle.
models. Section 9.7.5.3 describes how reliability can be incorporated into schedule-based models.

9.6.3 Capacity and bottlenecks
Relations between capacities, capacity utilisation (bottlenecks), and reliability are crucial for the performance of railway systems due to their inherent infrastructure properties. Capacity can be defined as the maximum number of trains in a railway section per time unit. It depends both on infrastructure (number of tracks, stations, and block sections) and on train services (speed, speed heterogeneity and scheduling). Capacity utilisation can be defined as the percentage time that a certain mix of trains utilises a section.

In metropolitan areas, the railway system often includes commuter trains, regional trains, and long-distance trains, which may compete for capacity in some bottleneck sections.

Railway performance is affected by both exogenous events leading to primary delays and endogenous repercussions in the system leading to secondary delays. The impact of such unexpected events depends on the scheduled delay, which is the buffer introduced in the timetable in comparison with the theoretical minimum running time under ideal conditions.

Travel time reliability will depend on how unexpected events and capacity utilisation affect the actual delays in the system. There is much evidence that passengers put higher disutility on unscheduled delays than on the scheduled running time known in advance. Hence, modelling of reliability and catering for the impacts of reliability on demand is important.

9.6.4 Access to outlying areas
For rail and public passenger transport, access to outlying areas relates to modelling of timetables and frequencies. As outlying areas typically have a small transport demand, timetable-based approaches are more suitable than frequency-based.

The main tendency in rail freight is a drastically increasing consolidation with fewer lines, services and terminals to obtain a higher degree of efficiency in the system. Access to outlying areas has therefore to be considered by hub-and-spoke systems, and multi-modal trip chains with truck services used for feeder modes.

9.6.5 High speed rail
Some models consider high-speed rail as a separate mode or sub-mode. It may – however – just as well be described by the travel time (as in the European TRANS-TOOLS model) and a special value of time (if this is justified for, e.g., comfort reasons). The special value of time may – however – also reflect non-linearities in the utility function with respect to time, why great care should be made when estimating models for high-speed rail. As fare levels are often higher per km in the high-speed lines versus the conventional, it is important to include ticket costs and income in the models for high-speed rail.

9.6.6 Rail freight models
Models for rail freight transport fall out in two categories:
9.7 Public transport – including urban public transport

Public transport assignment is in general more complex than road assignment (Brems, 2001). This is mainly because the transport is scheduled but also due to the need for multi-modal route choice models. Two important references are Lam and Bell (2003) about optimisation of public transport and Bell and Yasunori (2003) on regularity and punctuality.

The first concern with scheduled transport is how to model this schedule. For scheduled based traffic a third dimension can be added to Table 9.1 if the assignment uses timetables or frequencies. The approach using frequencies requires least data. An example of a frequency-based public transport assignment is given in Nielsen (2000). The benefit is that the network only has to hold travel time, cost, and frequencies. The problem with the frequency-based models is that transfers, regularity and capacity are poorly represented. Furthermore, aggregation of parallel lines is difficult. In regions were public transport is timetable-based this approach is more precise. The cost is a great amount of work has to be put into the network coding, which ideally should include the entire timetable. Furthermore, the future timetables need to be coded if scenarios are to be tested. Some of these problems can be eliminated through GIS-based methods to import timetables from operators into the model. The benefit is a much more detailed assignment.

A second concern in public transport assignment is the fact that in many urban and metropolitan areas a trip uses several (sub)modes. Hence, the way these different modes are described and interacted can be very complex.

A third issue in public transport assignment is how to deal with correlated alternatives and overlapping routes. In road networks, the definition of overlap is fairly simple being based on the length of overlapping paths, either in time or in distance. In contrast to road networks, however, route choice in public transport has multiple dimensions. There are many possibilities for overlapping components: such as nodes, modes, transport services, links, etc. From a behavioural perspective, routes using the same transport modes depend on one another. They share common unobserved aspects that are related to those specific transport modes. For example, consider two alternatives that both use bus for part of the trip. The same level of service, such as seating comfort, limited time accessibility, lack of privacy, and transport fees, is experienced on both alternatives.
In order to define route overlap in multi-modal transport networks, one should identify common route elements that are sources of correlation between routes (i.e., due to unobserved characteristics that are not included in the utility function). In public transport networks and in multi-modal networks, the following types of elements may be sources of correlation (Hoogendoorn-Lanser, 2005):

- nodes (origin, destination, boarding and alighting stops, and railway stations);
- modes: private, e.g., walk, bicycle, car, or public, e.g., bus tram, metro, train. The only exception to this rule is walk as access and egress to and from urban public transport, which is considered to be part of a urban public transport leg;
- Based on expected or scheduled travel time. Using actual travel times would have the theoretical disadvantage that overlap would vary as travel times vary over time for instance due to congestion or to service irregularities;
- Based on distance, the most straightforward type of definition.

9.7.1 Assumptions on passenger arrival

The arrival pattern of passengers into the public transport system is of importance to the modelling of waiting times. Normally, passengers can be assumed to arrive after one of two patterns: random arrival and timed arrival. From actual studies of waiting time at selected stops in suburban London, Jolliffe and Hutchinson (1975) find that the waiting time for passengers arriving at random can be split in two subgroups

- **Random arrival** The passengers arrive at random. Some of the passengers arrive at the same time as the vehicle. This is called coincidentally arrival. These passengers often hurry to the stop when seeing the vehicle at a distance. These passengers have no waiting time. The calculation of waiting time in general for random arriving passengers depends on the departure pattern of the vehicle (e.g., the variability in departure).

- **Timed arrival** The passengers arrive at a given time before the scheduled departure of the vehicle. They arrive as to minimise their (between days) expected waiting time. The waiting time depends on the between-day variability of the departure of the vehicle.

From the observed stops Jolliffe and Hutchinson (1975) found that the between-days variation of vehicle departures was too high to have any passengers using timed arrival. This makes all passengers arrive at random. From this group of passengers 16% are observed to have coincidental arrival. Marguier and Ceder (1984) refer to two similar studies from Paris. These studies also find that between-days variation is too high to have any passengers using timed arrival. The numbers they find on coincidental arrival is 10% and 15% of passengers, which is a little less than in London.

The proportion of passengers within each group depends on the headway of the line and the variability of departures between days. If the headway is small, more passengers tend to arrive at random since the obtained reduction in waiting time by knowing the timetable and timing the arrival is of no great importance. On the other hand, the longer the headway the greater...
The passengers have to time their arrival. This distinction by headway is included in the Greater Copenhagen Area Traffic Model. In this model, it is assumed that passengers arrive at random if the headway is 12 minutes or less. If the headway is more than 12 minutes, the passengers are assumed to time their arrival. O’Flaherty and Mangan (1970) also find headways of 12 minutes as the level where passengers change from random arrival to timed arrival. Bowman and Turnquist (1981) as well as Marguier and Ceder (1984) refer from different studies levels from 10 minutes in Manchester, 12 and 13 minutes in Chicago and Evanston to 18 minutes in Paris. Whilst the proportion of timed arrivals is assumed to increase with headway, it may also be assumed to decrease with an increase in between day variation of vehicle departures. If the vehicle departs at exactly the same time each day, regular passengers will tend to time their arrival. This is not possible if the departure of the vehicle varies significantly.

Furthermore, the amount of passengers having coincidental arrival can be assumed to increase if passengers are in some way notified by vehicle departure. A simple notification is the sight of a vehicle arriving (observed, e.g., at Alewife station in Boston) whereas a more sophisticated way of notifying passengers is signs stating the time of the next departure (observed, e.g., at Nørreport in Copenhagen). In the Alewife case, the passengers are notified by a glance from the top of the station down to the platform. If two trains are present at the platform the regular passengers know that one is going to depart within the next minute and passengers were observed rushing down the stairs to the platform. If only one train is present there is most probably more than one minute until the next departure.

In such cases, the arrival pattern at the station area may be random but the arrival pattern at the platform is closer to the pattern presented in Figure 9.6. Because of the higher number of coincidental arrivals, this form of arrival pattern has a smaller average waiting time than the general random arrival pattern.

From the characteristics of the two groups it can be concluded that passengers tend to arrive at random when headways are short or when the between day variation in departure time is high. This is most often the case for high frequency lines with no published timetable. These characteristics are often connected with subways of large metropolitan areas or with bus services in central city areas. Despite this limited relevance of the random arrival assumption, most models assume that all passengers arrive at random, i.e., passengers can be assumed to arrive after a uniform distribution function. The error of such assumptions is greatest for low frequent regular services, e.g., inter-city rail services.
9.7.2 Common lines

Sometimes different lines in the public transport system serve the same set of streets or sections of tracks, i.e., run in parallel for some part of the lines\textsuperscript{29}. Figure 9.7 shows an example with two lines running in parallel between stops A and B. For passengers boarding before stop A or alighting after stop B the current common line problem is of no interest, since only one of the lines serve the entire section. Whereas passengers travelling from A to B or between intervening stops may be indifferent of which line to board. In the latter case, the common line problem describes how these passengers choose among the common lines. Furthermore, if traffic should only be assigned at a corridor level, the actual choice between common lines is of no importance. In the latter situation, the aggregation of lines into a representative service is the important aspect.

![Figure 9.7: Common line problem](image)

Chriqui and Robillard (1975) is the main reference for dealing with the problem of common lines. In a case where a passenger can choose among several lines to get from A to B (as in Figure 9.7) they state the common line problem this way:

“A passenger in A will not use just any of the lines. Because some lines might have a very long in-vehicle time to reach B, the passenger may disregard them”

This statement says that a passenger in order to minimise expected total travel time might let a slow line pass because a faster line is expected soon after. The passenger’s ability to use this system depends on his/her knowledge of in-vehicle time, frequencies and/or timetables. The way to include such a strategy in a model is described in Chriqui and Robillard. The passenger forms a subset of lines, which minimise expected total travel time. The passenger may choose to board the first departing vehicle from one of the lines in the subset.

If the object is to minimise expected total travel time by finding the line that arrives to the destination first, there is no reason to deal with the common line problem in systems where overtaking is not possible. The Danish S-trains form such a system. Here the vehicle departing first from the boarding stop will be the vehicle arriving first at the alighting stop and thereby be the vehicle with the smallest expected waiting and in-vehicle time, when no weights are assigned to the time components. If weights are assigned, the longer in-vehicle time of the slow line may outweigh the longer waiting time of the fast line.

\textsuperscript{29} This section is based upon Brems (2001)
An example where the common line problem is of great importance is the introduction of new S-buses in the Copenhagen Area. Some of these lines serve exactly the same set of streets as other already existing lines. Only the new S-buses are express buses with fewer stops. Such two lines are shown in Figure 9.8. Line 39 and line 100S use exactly the same set of streets but as the timetable shows line 39 is an ordinary (slow) bus whilst line 100S is the express bus with shorter in-vehicle time from Haraldsgade to Nørrebro. While line 39 departs every 7.5 minutes line 100S departs every 6.5 minutes.

<table>
<thead>
<tr>
<th>line</th>
<th>Haraldsgade</th>
<th>Nørrebro</th>
<th>in-vehicle time</th>
<th>waiting time</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>2:15 PM</td>
<td>2:23 PM</td>
<td>8 min</td>
<td>-</td>
</tr>
<tr>
<td>100S</td>
<td>2:17 PM</td>
<td>2:23 PM</td>
<td>6 min</td>
<td>+ 2 min</td>
</tr>
</tbody>
</table>

Figure 9.8: Example of common line problem. From timetable winter 98/99

If the calculation of expected waiting and in-vehicle times are based on the timetable (and fixed timetables without delays are assumed) the waiting and in-vehicle time can be listed for every departure time of vehicles. For the example of line 39 and line 100S with passengers arriving at random and passengers having perfect information of the timetable, the amount of traffic assigned to each route is equal to the proportion of time the line is arriving first to the destination. This is not the same objective as minimising expected travel time but it is the closest to a reference for the model calculations. Say that a passenger arrives at Haraldsgade at 2:13 PM. The timetable in Figure 9.8 indicates that choosing line 39, which depart first would result in a total travel time of 10 minutes consisting of 2 minutes waiting time and 8 minutes in-vehicle time. If the passenger let line 39 pass and wait for line 100S it would also result in a total travel time of 10 minutes, only this time the waiting time would be 4 minutes and the in-vehicle time would be 6 minutes. In this case the choice between line 39 and line 100S would depend on the weighting of waiting time and in-vehicle time. If no weighting is applied, the passenger will be indifferent but if weighting is applied, the passenger will choose line 39 since this has the shortest waiting time. Passengers arriving after the departure of line 39 but before the departure of line 100S will all board line 100S. Following this pattern the distribution of passengers of the two lines is indicated in Table 9.5.

<table>
<thead>
<tr>
<th></th>
<th>line 39</th>
<th>indifferent</th>
<th>line 100S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timetable-based</td>
<td>15 %</td>
<td>20 %</td>
<td>65 %</td>
</tr>
</tbody>
</table>

Table 9.5: Distribution of traffic

To be able to select the subset of lines that minimises the expected waiting and in-vehicle times, expressions for average waiting and in-vehicle time have to be found. Chriqui and Robillard (1975) state some general probabilistic expressions for waiting time. Let \( y_i \) be the waiting time for the first vehicle of line \( l \) to depart and \( X = \{x_1, x_2, \ldots\} \) be the set of common lines. Let \( x_i \) be equal to 1 if line \( l \) is included in the subset of attractive lines. The waiting
The time for the departure of the first vehicle within the set of attractive lines can then be expressed as the minimum of waiting times for departure of first vehicle over lines

\[ W_X = \min_{l} y_l \]  \hspace{1cm} (9.31)

The expected value of \( W_X \), \( E(W_X) \), depends on the distributions of \( y_l \)'s and thereby on the departure pattern of line \( l \). Furthermore, the probability that line \( l \) will depart first can be expressed by

\[ H_l(X) = \text{prob} \left( y_l = \min_{i} y_i \mid X \right) \]  \hspace{1cm} (9.32)

the probability that the waiting time for line \( l \) is the shortest. Using these two components, the expected waiting time and the probability of a line departing first a general expression of expected total travel time could be written as

\[ T_X = E(W_X) + \sum_{l} t_l H_l(X), \]  \hspace{1cm} (9.33)

where \( t_l \) is the in-vehicle time for line \( l \). The subset referred to in the first statement of Chriqui and Robillard above is the set \( X \) that minimises the expression \( T_X \). The latter is a 0,1-optimisation problem, which can be solved by complete enumeration for small problems but gets very complicated when the number of lines increases.

The forms of \( E(W_X) \) and \( H_l(X) \) depend on the assumptions applied for arrival of passengers and departure of vehicles. The most common set of assumptions is that passengers arrive at random while the vehicles depart at fixed intervals. \( y_i \) is then uniformly distributed in the interval 0 to \( w_i \), where \( w_i \) is the headway of line \( l \). These assumptions yield the expression (formulated by Lambkin and Saalmans, 1967)

\[ T_X = M \left\{ \prod_{l} \left( 1 - \frac{x_i z}{w_i} \right) + \sum_{l} \frac{t_l x_i}{w_i} \prod_{i \neq l} \left( 1 - \frac{x_i z}{w_i} \right) \right\} dz \]  \hspace{1cm} (9.34)

where \( M = \min_{i} w_i \). The expression in (5.8) has to be minimised over the set \( X \).

In order to avoid solving the optimisation problem Chriqui and Robillard (1975) have developed a heuristic algorithm that produces optimal solutions when the \( y_i \)'s have identical distributions or when the in-vehicle times \( t_i \) are identical. They have not been able to prove optimality of the heuristic solution in any other cases. On the contrary, Marguier and Ceder (1984) find a set of counter examples.
The common line problem may be dealt with either in the network construction or in the route choice modelling. In the presentation of networks and route choice models examples of both can be seen.

9.7.3 Attributes on route choice for public transport

The most important attribute of route choice in public transport is travel time. The structure of the public transport system requires that the travel time consist of several different time components, e.g., in-vehicle time and waiting time. Different surveys show that passengers evaluate these time components differently wherefore it is important to keep track of each of the components. Often time components are the only attributes of route choice models in public transport. Other attributes may though be transfer penalty or regularity and comfort attributes. Dial (1971) has shown that the solution of an all-or-nothing assignment is very sensitive to the exact measuring of attributes while Hickman and Wilson (1995) have obtained similar results for more advanced route choice models.

9.7.3.1 Time components

A trip using public transport includes a line of different sub-trips as shown in Figure 9.9. Associated to each of them is a time component. For the example, the time components are access time, waiting time, in-vehicle time, transfer time, egress time and hidden waiting time. Depending on the modelling approach and purpose, most of the time components either can be found in a timetable or calculated using different expressions depending on the assumptions applied.

![Figure 9.9: Example of time use for a public transport trip](image)

The slope of each line in the figure shows the average speed for that part of the trip. It is seen that even though some public transport modes have a relatively high speed, the waiting and transfer times slow down the average speed for the whole trip.

In the following, each of the time components is described and modelling expressions suggested.
Access time
The access time is the time needed to get from the origin to the boarding stop of the first line in the public transport system. By this definition, the access mode cannot be another public transport mode but has to be an individual mode, i.e., walk, bike, car or the like. The access time cannot be found in a timetable but has to be calculated from the individual network or generated at an aggregate level for the current zone. The traditional way to calculate the access time in the former case is to multiply an overall mode speed with the distance generated from the network. For the latter case, the number of stops within the zone and the size of the zone can be used to generate some aggregated measure of access time for the zone. The latter method is not nearly as exact as the former.

Waiting time
The waiting time is by this definition the time the passenger spends waiting from the arrival at the first stop of the public transport system to the departure of the chosen vehicle. The actual waiting time depends on the arrival of the passenger, whether the passenger tries to time the arrival, the possible delay of the vehicle, etc. The expression of expected waiting time is trying to include as much of this information as possible. As described in Section 9.5.1 the expression used to calculate the expected waiting time depends on the assumptions of passenger arrival and strategy as well as vehicle departure and regularity. The expected waiting time also depends on the number of lines serving the relevant pair of stops since the availability of more lines usually results in more departures and thereby shorter waiting times.

For a stop with only a single line the traditional way of calculating expected waiting time is the simplest possible. The passengers are assumed to arrive at random and the vehicles are assumed to depart with equally fixed intervals of headway $H$. Furthermore, it is assumed that departures are perfectly regular and since only one line serves the stop, the passenger is assumed to board the first vehicle departing. In that case the expected waiting time is the well known

$$E(W) = \frac{1}{2}H$$

The expression can become a little more realistic by relaxing the assumption of perfect regularity. It is now assumed that vehicles depart with a mean headway $E(H)$ and a variance $Var(H)$. The passengers are still assumed to arrive at random and the vehicles with irregular intervals. In this situation the expected waiting time can be calculated as

$$E(W) = \frac{E(H^2)}{2E(H)} = \frac{E^2(H) + Var(H)}{2E(H)}$$

Compared to the above expression the expected headway increases with the introduction of irregularity as should be expected. If $Var(H) = 0$ in formula (9.36) corresponding to fixed headways, the expression of formula (9.35) is obtained.

The assumption of random arrival of passengers is acceptable if the headways are small and the service of the line is irregular. Otherwise, the passengers will tend to time their arrivals.
When this happens the expected waiting time can be found as the minimum expected waiting time given the headway and the irregularity of the line. If the expected waiting time becomes too small it is too risky to miss the departure of the vehicle and if the expected waiting time becomes too large, the waiting time is too disadvantageously.

The Greater Copenhagen Area Traffic Model assumes that passengers arrive at random if the headway is less than 12 minutes and time their arrival if it is more than 12 minutes. In the latter case, the waiting time is set to 6 minutes. Furthermore, a minimum waiting time is set to 1 minute. The final function describing the expected waiting time is presented in Figure 9.10.

![Figure 9.10: Calculation of waiting time](image)

When a passenger can choose between several lines at a stop, the waiting time is reduced. The average waiting time in that case is sometimes calculated as a generalisation of the simple single line waiting time in formula (9.35). The headway can also be expressed by the reciprocal of the frequency and the single line waiting time gets the form

\[
E(W) = \frac{1}{2f},
\]

(9.37)

where \( f \) is the frequency of the line. In the generalisation, the expected waiting time with several lines is just half of the reciprocal of the sum of frequencies, i.e.,

\[
E(W) = \frac{1}{2 \sum_{l \in L} f_l},
\]

(9.38)

where \( f_l \) is the frequency of line \( l \) in the set of attractive lines \( L \). Most often, though, the waiting time is only calculated for the single line and afterwards the expected waiting time is included along with other measures in a route choice model.

**In-vehicle time**

The in-vehicle time includes all time spent onboard public transport vehicles. If more lines or modes are used, the in-vehicle times for each are summarised. If stated preference analyses and/or a mode choice model show that passengers have significantly, different evaluation of in-vehicke time by different modes, the in-vehicle time should be kept separate for each mode.
It is often seen that passengers prefer one minute of in-vehicle time in train to one minute of in-vehicle time in bus. In this case, the evaluation of paths depends on the mode serving the path.

If regularity/punctuality is not considered, the in-vehicle time can be found from the timetable. Otherwise, a method to describe variation in in-vehicle time has to be applied. One way is to add a random number to the in-vehicle time describing the variation in time for the current lines. Finding a proper distribution should not be a problem since data on the vehicles’ driving times are already collected by the transport authorities to generate timetables and calculate on-time performance. These data show how many times and how much the vehicle is early or late. Based on such data a distribution with proper parameters can be chosen as a basis for generating variation at the present.

Another way, especially for buses, is to let the amount of other traffic on the streets used influence the driving time of the buses. In this way, congestion on streets caused by cars can be included in the calculation of in-vehicle times for buses. This is the first step towards a multi modal route choice model.

**Transfer time**
The transfer time consists of two parts, the physical transfer from the alighting stop of the first line to the boarding stop of the second line as well as a waiting time at the second stop before the departure of the second line.

![Figure 9.11: Illustration of a transfer](image)

The actual structure of a transfer is often disregarded and the transfer time is calculated in the same way as waiting time for the first boarding. In these cases, the expressions presented above for waiting time can be used. The approach introduces a certain amount of error in the model. Three main issues should be described in that connection. Firstly, as illustrated in Figure 9.11, not all transfer time is used for waiting which makes a minimum transfer time necessary. Secondly, the evaluation of the transfer time (in total) may differ from the evaluation of waiting time since some of the time has the purpose of transferring the passenger from one stop to another. Finally, the assumption of random arrival of passengers can be discussed since passengers arrive according to the arrival of the alighting lines.

Figure 9.11 is a more detailed illustration of what in Figure 9.9 is only denoted a transfer. It is seen that only part of the time is spent on waiting while some time is needed for the transfer. The role of the physical transfer is of cause larger for large terminals than for small stops where there may not be any distance between the alighting and the boarding stop. For each stop or terminal, it may be relevant to assign a minimum transfer time to get from one stop to another. The minimum transfer time either can be specified for the stop/terminal in general or
for each combination of lines since the actual placing of stops within the terminal is relevant for the minimum transfer time.

**Egress time**

The egress time is the time used to get from the alighting stop of the last line in the public transport system to the destination. Thus, the egress time is similar to the access time. Similar restrictions on modes exist – the egress mode has to be individual, i.e., walk, bike, car, etc.

The egress time can and shall be calculated in the same way as the access time.

**Hidden waiting time**

The hidden waiting time is sometimes omitted from route choice models. The hidden waiting time is a result of the restriction of public transport service in time. It is only of relevance when passengers have a fixed arrival time. This may require a passenger with a fixed arriving time to be early in order to get to the destination in time. Incorporating hidden waiting time requires data on the number of passengers with fixed arriving times for different purposes and at different times of the day. The hidden waiting time depends on the frequency of path. High frequency corresponds to small hidden waiting time. The calculation of hidden waiting time for passengers with fixed arrival time shall be based on the frequency of the path segment with the lowest frequency since this determines the frequency of the path. Thus, the hidden waiting time cannot be higher than the headway for this frequency.

### 9.7.4 Frequency-based models

Frequency-based models typically assume that passengers board departing lines according to their frequencies. This principle does not take coordination of lines into account, despite the fact that most transit companies aims at making transfers as efficient as possible. Another problem is that arrival processes are assumed following different kinds of statistical distributions or principles, which are not conditional on possible use of prior lines. Frequency-based models are more useful in high-frequency networks than in low-frequency networks, as the model simplifications are less crucial here.

Frequency-based models have – however – some benefits as well, e.g., the faster calculation times compared to schedule-based model and the reduced need of data coding of exact time-tables.

### 9.7.5 Schedule-based models

Schedule-based assignment models are able to model route choices in schedule-based networks more detailed than frequency-based models, but the data need and calculation complexity is also much larger. Schedule-based models have been used more in practice during the last 10 years. A combination of factors has eased the use of such models:

- The constant evolution of computer hardware both with respect to calculation efficiency and memory (RAM).
- Improvement of solution algorithms, whereby computer power is utilised more efficient.
- The availability of powerful Geographical Information Systems (GIS) to handle the data involved.
The fact that the necessary timetable data are now often available in accessible electronic formats that can be imported into the models. Schedule-based models are however still very calculation demanding, and slow for large-scale applications (Nielsen, 2004). This is especially the case, if the models apply stochastic route choice principles, such as in Nielsen and Frederiksen (2006). Calculation times are therefore a significant hindrance for a more widespread use of schedule-based models. The article focuses therefore on different ways of making the solution algorithms in schedule-based models more efficient.

9.7.5.1 Model types

In general, the majority of schedule-based assignment models assume the timetable to be deterministic – i.e., with no delays (refer to the classification in Table 9.6). The route choice models are often deterministic as well, i.e., they assume a deterministic choice behaviour of the passengers. However, especially during the last 5-10 years stochastic schedule-based models have emerged (refer to the review in Nuzzolo and Crisalli, 2004). While the earlier stochastic choice models applied the logit model, the newer accounts for overlapping routes. Examples are the approach applied in Friedrich and Wekech (2004), path-size logit (Hoogendoorn-Lanser, 2005, including a thorough literature review of this subject) or Probit (Nielsen, 2004a). An additional feature is the use of random coefficients such as in Nielsen and Jovicic (1999). Mabit and Nielsen (2006) developed this further to take correlation of taste preferences into account.

<table>
<thead>
<tr>
<th>Delay considerations</th>
<th>Deterministic route choice model</th>
<th>Stochastic route choice model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No capacity restrictions</td>
<td>Within coach capacity restrictions</td>
</tr>
<tr>
<td>Deterministic timetable</td>
<td>Majority of schedule-based assignment methods</td>
<td>Some applications</td>
</tr>
<tr>
<td>Timetable with delays</td>
<td>Full a priori knowledge</td>
<td>In principle as the deterministic methods, but run on the delayed timetable, e.g., Hickman and Bernstein (1997, principle 4)</td>
</tr>
<tr>
<td>On-route decisions</td>
<td>Hickman and Bernstein (1997, principle 3)</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 9.6: Classification of schedule-based assignment problems

30 Reconsideration for the en-route run choice at stop.
A few models also consider within coach capacity restrictions such as getting seats or not (Nielsen et al., 2001) or overloaded coaches (rejection of passengers who want to board). A review of the literature is given in Nuzzolo and Crisalli (2004). De Cea and Fernandez (1993) and Kurauchi et al. (2003) are examples on capacity-restricted models. Rejections of passengers may be more relevant for urban bus transport, long distance rail transport, air transport or freight transport in schedule-based networks than for suburban rail lines, which seldom reject passengers. However, an important point is that capacity problems may be more relevant in networks with delays due to arrival processes of passengers. If passengers are arriving partly uniformly distributed, more are expected to board the delayed services. If passengers from one service loose their connection, then the number of transferring passengers may be doubled when the next connection arrives.

9.7.5.2 Model components

Schedule-based assignment models often consist of the following elements;

1. A graph search algorithm that find optimal paths in a schedule-based network given a certain choice function. As this is the building block of the solution algorithm, the overall calculation time complexity is close to linearly depending on the calculation time of the graph search.

2. A choice model. The more recent models adapt Random Utility Models for public transport assignment (e.g., Nielsen, 2000), whilst earlier models used heuristic principles or rules, e.g. all passengers taking the first departure. In the following, we only investigate stochastic assignment models that build on Random Utility Theory.

3. Equilibrium scheme. Schedule-based models that consider capacity restrictions – e.g., seat possibilities (Nielsen et al., 2001) or rejections when boarding (Nielsen et al., 2007a) needs an equilibrium algorithm to be solved. The most used principle is the User Equilibrium (UE), and when combined with a stochastic model this becomes a Stochastic User Equilibrium (SUE), Sheffi (1985).

Nielsen and Frederiksen (2007) provides an overview of these components and how they can be optimised in a schedule-based model.

9.7.5.3 Modelling reliability

Concerning route choice modelling of networks with delays, a few prior models have been identified. While Nuzzolo and Crisalli (2004) provide a classification scheme for irregular services (Ibid, Table 5.1), only few references are given, mainly to Hickman and Bernstein (1997). In addition to this, Bates et al. (2001) define some principles for the problems of unreliability and interchange journeys.

Earlier models (1st generation delay models) assumed full knowledge on the present and future delays. An example is the fourth path choice principle in Hickman and Bernstein (1997, p. 143). In principle, this is similar to run a deterministic timetable-based model on the delayed network, and then compare this to the same model run on the non-delayed network. This is a “pseudo” delay model, since it has no assumptions on passenger behaviour or on-trip re-routing if trains
are delayed. The route choice principles can therefore – in principle – be identical to the deterministic schedule-based methods.

An improvement of the 1.generation model was applied in Ildensborg-Hansen (2006) where passengers are assumed to arrive at the departing station according to their a priory choices. However, from then on full knowledge is assumed. In Nielsen et al. (2007b), they classify this approach as a 1½-generation model. Nuzzolo and Crisalli (2004, p.15) also assumes a re-consideration at the stop (here in a bus-network application) given knowledge from a passenger information system31.

Nuzzolo et al. (1997) proposed a method to simulate transit irregularity and to apply a schedule-based route choice model on the irregular timetables. The approach may be considered somewhat similar to that of Nielsen and Frederiksen. (2001), i.e., that passengers implicitly are assumed to know the delay distribution. In Nielsen et al. (2007b), they classify this as a second generation models, as passengers are assumed to know the delay distribution a priori, and then choose route pre-trip according to the expected delay distribution.

9.8 Air transport

Although the focus is regional modelling, air transport may play a significant role in national models. Furthermore, choice of access mode to airports may play a role in regional models as well. As an example, better access to some larger or cheaper airports by high-speed rail or new motorways may lead to shift of airports and use of other feeder modes. In some regional projects – e.g., the Øresund Bridge and the new high-speed railway between Amsterdam and Rotterdam – traffic to airports (Kastrup, Schiphol) play a significant role. Similar issues may emerge in the new member states.

9.8.1 Passenger

Few transport models include air-route choice. The TRANS-TOOLS model envisioned to model all passenger modes; i.e., passenger cars, rail transport, and air. The model, however, operates at a NUTS 3 level, whilst the main airports have their hinterland from several NUTS 3 and other airport competes even within each NUTS 3 It is therefore also necessary to model the access-modes to airports, i.e., mainly car versus train. In some cases, access to major hubs may even include competition between rail and air, e.g., Lyon to New York, where both rail (TGV) and air can be used to Paris. The access modes may also describe inconvenient access to low price airports versus easier access to more expensive airports, e.g., London Luton versus Heathrow.

Three main modelling approaches may be followed to model access modes to airports:

1. Creating a multi-modal assignment model for air and access modes (i.e., a hyper network approach).
2. Using a discrete choice modelling approach (e.g., a logit model).

31 In a quite advanced traffic information system context at the Island of Ischia, Italy.
3. Using a combined approach, where a multi-modal assignment model is used at a more aggregated pseudo network level.

While the first approach might be quite elegant, especially since it can describe overlapping and correlated alternatives, it has several disadvantages:

1. The multi-modal network becomes huge at a European level, and the calculation time would therefore become infeasible.

2. It would require quite a work effort to code the transfer points in a multi-modal network model.

3. The model would be difficult to estimate and calibrate, contrary to a logit modelling approach, where it is easier to fulfil logical restrictions.

4. The model would require new software development.

While TRANS-TOOLS used a link-based approach, the Greenland Air Transport model (Nielsen et al., 2007) used a schedule-based approach incorporating principles from public transport models but adapted to the air market. This model also optimised schedules by linking the route choice model to an optimisation model.

9.8.2 Air freight

As airfreight is only a small market compared to the other modes and since the main focus of the project is regional modelling, this section is very brief. Airfreight transport is not modelled in terms of freight demand. In some aggregate freight models like NEAC, it is included in the database as a rest category together with other modes that have non-competing segments (such as pipelines and air transport). Air transport has usually its own segment in transportation that has limited or no competition at all. Usually a fast transport is necessary because the value of time is very high. Thus, usually high value products are transported by air. An exception to the rule is that low valued products can be transported by air transport in case of urgencies in the production process\(^\text{32}\).

\(^{32}\) A famous example is a pipeline company that transported 3 747 loads from Europe to Argentina with tar, this was done in order not to stop the pipeline building process, the tar was needed as coating for the pipeline.
10 Socio-economic assessment methods

In the last decade, there has been an increased focus on socio-economic impact assessments of significant infrastructure projects in the road sector. Further, environmental impacts assessment is constantly being demanded, due to the increased debate about the environmental impact of road traffic. This has in turn increased the requirements placed on the socio-economic assessment methods.

Transport models provide information about changes in transport due to, e.g., changes in the infrastructure. It is difficult to assess whether some change is beneficial or not simply based on the outputs of transport models. Moreover, it is difficult to assess benefits and costs of transport investments.

The socio-economic assessment is intended to provide a comprehensive evaluation of a given project’s profitability; however, there are always considerable uncertainties associated with such analyses. It is therefore important that the focus of investigation encompass more than mere numbers such as net present values or internal rate of return. Further, it is crucial that the analysis also identifies the critical factors for the outcome of the evaluation of profitability.

Another important aspect of a good socio-economic assessment is that it must provide a systematic and transparent accounting of the project’s benefits and costs, thereby contributing to openness in the decision-making process. The difficulties in assessing projects are according to ECMT (2001):

- Effects of different investments and other measures have to be studied empirically, and generalisations from one case to another leads to uncertainties.
- There are many different approaches to benefit calculation. The proposed methods can differ depending on the analysis’ research fields and the purpose of the assessment.
- Unlike products sold in the private market, the benefits of transport often do not have a monetary value on an actual market.
- The development of regions and countries is influenced by a wide range of factors, of which transport is one. It is always difficult to judge which single factor is most important, and sometimes meaningless.
- Valuing different effects, positive and negative, in monetary terms cannot be made in a general way, but is dependent on current national policy and other economic circumstances. There may also be factors that cannot or should not be valued in economic terms.

To ensure that socio-economic project evaluations can serve their intended purpose as instruments for supporting decisions regarding the prioritisation of projects it is fundamental that consistent principles are applied to all of the projects included in this prioritisation. The increased emphasis on socio-economic methods as a significant decision-making tool has also resulted in a greater focus on being able to apply these methods in relation to the different forms of transport (and sectors).
10.1 Assessment methods – general characteristics

The descriptions in this section are primarily based on two reports: ECMT (2001) and Lyk-Jensen (2007), where further details on the issues can be found. Many types of assessments are used in different countries. The following list summarises them:

1. The engineering perspective focuses on the capacity standard of the network (the transport models).
2. Political measures based on voting outcomes, which are an unavoidable part of the decision process in any democratic country.
3. Geographical localisation/regional development, which is concerned with where the effects of the investment are happening.
4. Economic estimates of productivity impact use a macro-economic perspective for measuring benefits from investments. The focus is on the growth in a region or country. The models or methods that fall in this category are covered in Chapter 8.
5. Civic planning, which focuses on how the infrastructure interacts with the structure of cities. The assessment focuses on urban sprawl related to investments in infrastructure, housing, and other land-use effects.
6. Economic measure of rates of return encompasses cost-benefit analysis and other micro-economic tools. This method will be described in more detail below.
7. Multi-dimensional Comparison (MDC) where each included impact is defined in monetary terms, quantitative terms, or qualitative terms following well-defined, systematic principles.
8. Multi-criteria analysis (MCA), where a weighting is made using weights based on, e.g., decision makers’ ranking of different criteria. Different projects will be ranked according to these criteria.

Figure 10.1: Appraisal methodologies, Source: Lyk-Jensen (2007)
Economic assessment can be done using one or more of approaches 4, 6, 7, and 8. Actually, MDC is a precondition for both cost-benefit analysis (CBA) and MCA. Furthermore, CBA can be regarded as a special type of MCA, where empirically based appraisals are applied in relation to all impacts. Conversely, a MCA always involves an implicit appraisal of all impacts, insofar as one of the impacts is calculated in monetary units. The distinction between CBA and MCA is therefore somewhat vague; in most countries, project assessments are conducted in some combination of all three methods. Attempt is made at illustrating this in the figure above.

A given overall assessment method can be characterised by placement within the triangle. Assessment methods will be placed higher in the figure proportionate to how often the weighting is used and correspondingly lower the less often this weighting takes place with valuation. Along the edge of the triangle:

- All of the impacts are weighted together along the top edge.
- CBA is not used at all in weighing the impacts along the right edge.
- CBA alone is used in the weighting along the left edge.

For those impacts that are not weighted, one can further distinguish between three various systematic calculation methods:

- Quantitative evaluation on a cardinal scale, i.e., that it makes sense to say that the value 6.4 on the scale is twice as good as the value 3.2.
- Qualitative evaluation, where the evaluation is converted to an ordinal scale, making it possible to conduct a ranking of projects on the basis of the criteria in question. The scale does not necessarily need to be expressed in numbers, but must be categorised, e.g., in a number of ‘+s’ or ‘−s’ or previously defined adjectives.
- Verbal description, where the impacts of the project on a given area are described in words on the basis of a number of criteria, which are constant from project to project.

The macro-economic method (method 4 in the list above) to evaluate the effects on production from investments in infrastructure is closely linked to the estimation using time-series or cross-section data as described in Chapter 8. The discussion about these effects is also contained in Bannister and Berechman (2000), who demonstrate that the production growth effects are only related to the investments if certain preconditions are fulfilled:

- The new infrastructure must be a significant improvement in the existing infrastructure.
- The new infrastructure must be accompanied by investments, locally.
- There must be a well-functioning local economy, where activities are supported politically.

Nevertheless, there has been several studies estimating the investment elasticities on production. ECMT (2001) reports a review undertaken by the US Department for Transport in 1992. Even though this is not new, there has not been large changes in the obtained elasticities apart from more studies and other methods used. The primary lesson to be learned from the review (Table 10.1 from ECMT, 2001) is the large variety in the elasticities.
<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Spatial level</th>
<th>Infrastructure variable</th>
<th>Productivity variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashauer (1989)</td>
<td>0.39</td>
<td>National</td>
<td>Public capital</td>
</tr>
<tr>
<td>Munnell (1990)</td>
<td>0.33</td>
<td>National</td>
<td>Public capital</td>
</tr>
<tr>
<td>Ashauer (1989)</td>
<td>0.24</td>
<td>National</td>
<td>Core public capital</td>
</tr>
<tr>
<td>Lynde and Richmond (1991)</td>
<td>0.20</td>
<td>National</td>
<td>Public capital</td>
</tr>
<tr>
<td>Hultén and Schwab (1991)</td>
<td>0.03</td>
<td>National</td>
<td>Public capital</td>
</tr>
<tr>
<td>Moonaw and Williams (1991)</td>
<td>0.25</td>
<td>State</td>
<td>Highway density</td>
</tr>
<tr>
<td>Costa, Ellson and Martin (1987)</td>
<td>0.20</td>
<td>State</td>
<td>Public capital</td>
</tr>
<tr>
<td>Munnell (1990)</td>
<td>0.15</td>
<td>State</td>
<td>Public capital</td>
</tr>
<tr>
<td>Munnell (1990)</td>
<td>0.06</td>
<td>State</td>
<td>Highway capital</td>
</tr>
<tr>
<td>Garcia-Milà and McGuire (2001)</td>
<td>0.04</td>
<td>State</td>
<td>Highway capital</td>
</tr>
<tr>
<td>Deno (1998)</td>
<td>0.31</td>
<td>Urban</td>
<td>Highway capital</td>
</tr>
<tr>
<td>Duffy-Deno and Eberts (1989)</td>
<td>0.08</td>
<td>Urban</td>
<td>Public capital</td>
</tr>
<tr>
<td>Eberts (1986)</td>
<td>0.03</td>
<td>Urban</td>
<td>Core public capital</td>
</tr>
</tbody>
</table>

Table 10.1: Output elasticities derived from aggregated production functions

Which method should be used? The macro-economic (productivity) approach or the CBA approach? The detailed content of the CBA approach will be covered in the following section, but the differences can be highlighted here. The macro-economic approach only concerns purely economic effects that only to a limited extent include externalities.

<table>
<thead>
<tr>
<th>CBA</th>
<th>Both</th>
<th>GPD productivity approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time savings for private transport</td>
<td>Company opportunity cost for business travel time</td>
<td>Multiplier effects in terms of increased productivity</td>
</tr>
<tr>
<td>Private opportunity costs for business travel time</td>
<td>Changes in vehicle costs</td>
<td></td>
</tr>
<tr>
<td>Accident risk reduction</td>
<td>Changes in maintenance costs</td>
<td></td>
</tr>
<tr>
<td>Environmental costs</td>
<td>Changes in accident costs due to loss in production, health care etc.</td>
<td></td>
</tr>
<tr>
<td>Part of changes in noise costs</td>
<td>Part of changes in noise costs</td>
<td></td>
</tr>
</tbody>
</table>

Table 10.2: Effects in CBA, Macro economic production/GDP based analysis and both
The CBA on the other hand does not necessarily include the second order effects in other sectors due to market imperfections. A summary of the main differences is shown in Table 10.2.

The two approaches do to a large extent measure different types of economic effects, but there are common elements. The welfare economic elements are mainly covered in the CBA approach, whereas many positive derived (multiplier) effects are covered in the macro-economic approach. The two approaches are thus complementary. However, in transport assessments we often only look at the CBA approach, which in some cases are modified to include some of the derived effects as well.

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Proposed evaluation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Core impacts&quot;</td>
<td></td>
</tr>
<tr>
<td>1. Investments</td>
<td>CBA</td>
</tr>
<tr>
<td>2. System operating and maintenance cost</td>
<td></td>
</tr>
<tr>
<td>3. Vehicle operating costs (fuel, wear and tear, repairs)</td>
<td></td>
</tr>
<tr>
<td>4. Travel time savings</td>
<td></td>
</tr>
<tr>
<td>5. Safety</td>
<td></td>
</tr>
<tr>
<td>6. Local environment (local air pollution, noise, severance)</td>
<td></td>
</tr>
<tr>
<td>&quot;Non-core, non-strategic impacts&quot;</td>
<td>MCA</td>
</tr>
<tr>
<td>7. Driver convenience (comfort, stress)</td>
<td></td>
</tr>
<tr>
<td>8. Landscape and urban quality</td>
<td></td>
</tr>
<tr>
<td>&quot;Non-core, strategic impacts&quot;</td>
<td>(MCA)¹</td>
</tr>
<tr>
<td>9. Strategic mobility (accessibility and networks)</td>
<td></td>
</tr>
<tr>
<td>10. Strategic environment (greenhouse gases, ecological damage)</td>
<td></td>
</tr>
<tr>
<td>11. Strategic economic development (regional effects)</td>
<td></td>
</tr>
<tr>
<td>12. Other strategic policy and planning impacts</td>
<td></td>
</tr>
</tbody>
</table>

Table 10.3: EUNETs evaluation methodology for inter-urban infrastructure road projects

(1) (MCA) = Dependent on the size of the project (Source: ECMT, 2001)

10.1.1 Socio-economic cost-benefit analysis
Following up from the comparison between macro-economic and CBA approaches and the differences between them, we can start the discussion about CBA to discuss which effects are included.
The answer to this question is “Theoretically, all benefits and costs”. However, that is not the general practice. One criterion for inclusion is a characterisation of effects as being direct, derived, or more overriding impacts. These criteria have been used in the EU project EUNET\textsuperscript{33}, which found a categorisation as illustrated in Table 10.3. The table shows the categorisation for inter-urban projects, but only in rare cases would this be different for other types of projects.

In practice, CBA encounters greater difficulty dealing with the impacts when moving from "Core impacts" to "Non-core, non-strategic" and further to "Non-core, strategic", where there is talk of more indirect impacts. Within "Core impacts", the monetary valuation becomes more uncertain – and the need for sensitivity analyses therefore becomes more important – as one proceeds down the list. In the case of the "Non-core" impacts, it is difficult to make any recommendation of well-established methods for the appraisal of these impacts. What is therefore up for consideration is whether one will utilise MCA to include these impacts or merely present them beside the CBA, i.e., whether one will move along the left or right edges in Figure 10.1.

An interesting question is whether the strategic effect "regional economic development" is a further advantage in addition to the time savings that are included in the traditional cost-benefit methods. This is an often-used – but controversial – argument for concrete infrastructure projects. This matter is dealt with in the ECMT report. The conclusion is that there can be further impacts, to the extent that the market situation in the transport sector and transport-reliant sectors deviates from the "ideal" with perfect competition; however, two significant points are:

- that the impacts can be both negative and positive; and
- that positive impacts do not necessarily fall in the (periphery) area for which accessibility is improved by the infrastructure project.

In any case, this aspect ought to be included in the basis for decision-making for major infrastructure projects.

10.1.1.1 The general approach

CBA can as mentioned, be done in many different ways. It is therefore necessary to know the conditions behind and assumptions made for each assessment. Major factors that lead to wrong interpretation in comparisons are:

- measure used: benefit/cost ratios of different kinds or rate of return measure
- evaluation period
- discount rate
- traffic forecast
- economic value of different parameters

Many countries have due to such difficulties in comparisons developed CBA manuals. The COBA manual in the UK is perhaps one of the first guides. The Scandinavian countries have

\textsuperscript{33} Nellthorpe et al. (1998) and ECMT (2001).
similarly developed guidelines highlighting methods and elements that must be covered (e.g., Danish Ministry of Transport, 2003). Moreover, many countries publish values for key factors (e.g., discount rates, evaluation periods, value of time savings, value of externalities, etc.) that further make inter-project comparisons more consistent. Most of such key values are distinctive for each country because individual effects in a country play important roles for the determination of the values. The methods for estimating these key values are described in Chapter 11. We will not discuss further, how the different cost and benefit elements are calculated. The calculations are input to the assessment and are linked to the transport models and methods for monetary valuation of, e.g., non-market goods. Instead we will look at how costs and benefits are compared in the evaluation criteria.

In general, costs and benefits are compared in a base year, to which all future costs and benefits have been discounted. The discount factor plays a crucial role in the calculation of the present values. A high discount factor puts higher emphasis on costs and benefits in the beginning of the period relative to future costs and benefits. The discount rates vary between 2% (risk free) in Norway to 6% in Denmark. The average is 3% in the countries reviewed in the HEATCO project34.

The most common valuation criteria are the Net Present Value (NPV) that measures the present value of the benefits minus the present value of the costs. A positive NPV indicates that a project results in higher economic welfare than the costs involved in the project. A complementary measure is the ratio of the NPV to the public financial costs of the project:

\[
\frac{PV_B - PV_C}{PV_{PC}},
\]

where \(PV_B\) is the present value of the benefits, \(PV_C\) is the present value of the project costs and \(PV_{PC}\) is the present value of the public costs needed to finance the project (including future capital requirements). The present values can be found using the formula:

\[
PV_B = \sum_{t=0}^{T} \frac{B_t}{(1-\delta)^t}.
\]

It is also common to calculate the rate of return that describes the average return on the investment. It represents the discount rate that would produce a NPV of zero for the evaluation period. The rate of return measures the same as the NPV. A high rate of return equals a positive NPV and vice versa. Some countries calculate the first year of return. This is calculated by discounting future costs to the base year, but only including the benefits from the first year. This measure can be used to determine an optimal year of implementation of the project.

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34 HEATCO – Developing Harmonised European Approaches for Transport Costing and Project Assessment, http://heatco.ier.uni-stuttgart.de/
Table 10.4: General technical economic methodological issues

(1) C/B = Cost-benefit ratio; NPV = Net present value; FYB = First year benefit; IRR = Internal rate of return; NBCR: Net benefit cost ratio. RNPSS: Ratio of NPV and Public sector support

There are differences between countries on a number of issues. General recommendations are found in the HEATCO project. However, the HEATCO recommendations do not reflect the latest developments in all aspects. There is a general tendency for countries having recently undertaken a revision of their methods to make use of market prices instead of factor prices. For example, The United Kingdom shifted to market prices in 1999.

Finland is the only Nordic country using factor prices. Finland uses an indirect tax correction of 22%. However, as long as there is consistency in the economic assessment measuring all values in either factor prices or market prices, the choice does not change the ranking of the projects.

There is a certain difference in terms of how distorting effects in connection with public financed investments are to be dealt with. Sweden has worked extensively with this matter and has defined two tax factors. Tax factor I that is added to the costs in factor prices in order to grant consideration to the value added (in market prices) that the production factors alternatively could have created. This corresponds to the indirect tax correction factor of the Danish Ministry of Finance. Tax factor II (supplementary charge of 30%) grants

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35 The RNPSS is defined as the ratio between the NPV of the whole project and the financial costs that have to be paid out of a constrained budget of the state. This decision criterion is used when the state wants to select between different acceptable projects, but cannot finance all of them because its budget constraints, see HEATCO, deliverable 2 for further details.
consideration to the circumstance that the publicly financed measures and projects are to be financed via taxation payments (which corresponds to the marginal cost of public fund).

In Norway, consideration is also granted to the marginal cost of public fund (or dead-weight loss) that they assess to be 20%. Incidentally, 25% is used in USA, cf. The Danish Ministry of Finance guidelines for socio-economic assessments, see Danish Ministry of Finance (1999).

Lyk-Jensen (2007) and ECMT (2001) further discuss differences and more detailed approaches to the calculation of specific elements of the CBA. A particular focus is on how the user benefits are measured (especially the Value of time). The methodologies for achieving such values are discussed in the preceding chapters.

10.1.1.2 The strengths of CBA

The appealing features of the CBA are quite convincing and well known. Hence, they are only briefly mentioned here. They may be categorised according to the following overall bullets:

- Transparency
- Comparability / consistency
- Ignorance revelation (through systematic collection of information)

Firstly, the CBA converts all social implications into an absolute monetary measure of the social profitability. It is desirable to be able to sum up all aspects of the decision problem in one simple value.

Secondly, the CBA provides a methodological tool for comparing projects and/or alternatives. This makes it a powerful decision support tool in the planning process; the values on cost and benefit elements are consistent between investments and over time. This means that the social profitability of projects or policies can be compared across sectors and at different points in time.

Thirdly, the CBA requires the collection of detailed information of financial as well as social costs and benefits. This gathering of information improves the basis on which the decision is made and may give valuable insight into the level of ignorance regarding important aspects of the evaluated project or policy.

10.1.1.3 The weaknesses of CBA

There are of course also problems associated with the CBA method. In short these may be categorised according to the following bullets:

- “False” transparency
- Practical measurement problems
- Inter-generational equity (sustainability)
- Social equity
Firstly, it is difficult to maintain consistency between the theoretical assumptions of the CBA method and the practical application of it, due to the fact that there may be problems involved when estimating unit prices for non-marketed impacts such as travel time savings, emissions, safety, etc. In practice, therefore, compromises are often made on the valuation of such non-marketed impacts, implying that the resulting unit prices are inherently of a subjective nature – without such subjectivities being visible in the evaluation. This is a problem with the CBA method since the presentation of a single evaluation measure thus implies a “false air of objectivity”.

In addition, what is seen by most economists as one of the great advantages of CBA, namely its great transparency, is argued by others as the exact opposite: All financial, environmental, and social considerations are reduced to a single number – thereby shielding the results behind a technical mystique. This disagreement could be argued as being a matter of taste, but it is a real problem if the public perceives the evaluation method as some kind of “black box”.

Secondly, there are impacts that can hardly be quantified or for which it is difficult or even impossible to estimate unit prices. These are especially impacts of a more long term and/or strategic nature – as for example many environmental impacts.

Thirdly, an important philosophical and moral problem in the evaluation of (long term) impacts is that the present generation values an impact that they may not live to experience. This means that they are valuing such impacts on behalf of the future generation(s). We will return to this distributional effect below.

The final problem with CBA to be mentioned here is that of social equity. This can be divided into three separate questions:

- The first critique relates to the individual welfare measurements: When valuing costs and benefits methods based on individuals’ willingness to pay are often used. As people’s willingness to pay will be intimately linked with their ability to pay, the market can be seen as a system that advantages those most able to pay. Hence using the market, whether an actual market or a contrived one, tends to produce values that reflect the existing distribution of income. This can be argued as an equity problem.

- The second critique relates to the aggregation of individual welfare measures into one of social welfare: In its conventional form, CBA is about aggregated (and unweighted) costs and benefits and does not deal with the issue of how they are distributed – although this is of prime concern when considering equity. As long as the sum of benefits outweighs the sum of costs (no matter who or how few people get the benefits and who or how many people suffer the costs) the society as a whole is assumed to be better off.

Some argue that in principle the CBA does not presuppose that individuals are treated anonymously – that is with equal weight in the aggregation of individual welfare into a measure of social welfare. In theory, one could aggregate individual welfare measures in a way (i.e. with weights) reflecting relevant equity concerns. However, as there is no established “right” to equity in the distribution of individual welfare, where would a decision...
maker get the needed weights? No unique set of “equity weights” exists, and therefore anonymous aggregation has become the default in CBA.

- The third critique is that although the method rests on the aggregation of individuals’ willingness to pay, no actual payment takes place and no actual redistribution of money results. Hence, the socio-economic optimum resulting from the CBA could be argued on equity grounds as being somewhat hypothetical.

10.1.2 Multi-criteria analysis

In MCA, the relative values of different criteria are explicitly subjective – as opposed to the CBA where unit prices reflect some sort of objectivity.

Hence, MCA methods presuppose a preference structure giving preferences on the different criteria. It is emphasised that with an assumption of such a preference structure the methods depend very much on the personality of the decision maker and the circumstances in which the decision process takes place. The purpose of a MCA is therefore not searching for some kind of hidden truth – but rather to assist the decision maker in mastering the (often complex) data involved and advance towards a solution (Gissel, 1999). Therefore, we prefer to refer to MCA as a decision aiding tool.

Multi-criteria decision problems can be naturally divided into problems concerning multiple objectives and problems concerning multiple attributes. In this report the focus is on decision problems of the second kind – that is, decision problems with given alternatives described by their multiple criteria (or characteristics).

In general, the essence of decision analysis is to break down complicated decisions into smaller pieces that can be dealt with individually and then recombined in a logical way. For the MCA methods there are basically three such distinct pieces: the set of possible alternatives, their characteristics (represented by a set of criteria), and the preference structure of the decision maker(s) – reflected in criteria weights.

Generally, the alternatives and their criteria represent the objective part of the decision process, whereas the subjective part of the decision process lies in the preference structure. However, in the case where a given criterion cannot be quantified in an obvious way, the decision maker and the analyst may be forced to make subjective assessments of the criteria scores, or they will have to find a surrogate measure that can function as a good proxy for the criteria. As discussed in Gissel (1999) the use of proxies should be preferred to subjective scores whenever possible. The principal argument for this is to restrict the subjectivity in the decision process to elements for which a constructive exchange of (political) opinion can take place.

There exists a wide variety of MCA methods representing a corresponding variety in methodological approach. However, the fundamental structure of the methods is generally the same.
10.1.2.1 The strengths of MCA

The strengths of the MCA may be summarised in the following:

- MCA overcomes most measurement problems
- Participation of the decision maker(s)
- MCA can be accommodated to address equity concerns

Firstly, MCA overcomes the difficulty of translating all values into monetary units by using subjective weights. In addition, both qualitative and quantitative indicators can be used depending on the criteria, and the time and resources available. That is, if an impact cannot be quantified (be it because of scarcity of time or resources or not) it may instead be represented by some sort of indicator (a proxy or a subjective score).

Secondly, stakeholders can be involved throughout the decision-making process to determine the alternatives and criteria, the criteria weights, and to score and determine the best solution. The technique offers – in fact it often requires – a more participatory approach as it takes decisions out of the hands of analysts and puts it with those stakeholders involved.

Thirdly, MCA can address equity concerns by incorporating equity criteria into the analysis, and it allows each individual the same representation, unlike the market (i.e., CBA) where those with greater money exert greater influence.

MCA may be seen as an extension of the CBA. In practice, the CBA represents only a part of the decision making basis; other non-monetised impacts represent another, and the final choice is based on a weighing of these different parts. Using only CBA this weighing may be completely opaque. The MCA methods offer a tool for approaching the subjectivities in the decision process and for reaching a decision in a methodological and transparent way. In MCA, both the monetised impacts of the CBA as well as more strategic impacts can be accommodated in one approach.

10.1.2.2 The weaknesses of MCA

Of course, there are also problems associated with the use of MCA. In short these may be presented as the following:

- The method can give no “absolute” measure of “goodness” – it is a tool for comparative evaluation only.
- The participatory nature of the MCA makes it both time and resource intensive.
- Difficulties in deriving criteria weights.

Firstly, the method is a tool for comparative evaluation only, as it gives no absolute measure of the “goodness” of the project or policy as does the CBA with its socio-economic profitability. This makes MCA a tool for deciding between options and not for a “go/no-go” decision.

Secondly, the active involvement of the decision maker(s) makes the MCA both time and resource intensive as it requires much from decision makers. However, in our opinion, this
should not necessarily be seen as a drawback of the method. Decisions are seldom objective, and if subjective judgments are present these should be transparent – at least to the decision maker himself. MCA offers a tool for obtaining this insight.

Thirdly, there can be problems with the elicitation of criteria weights. The analyst should be very aware that the derivation of weights is a fundamental and critical step in the MCA. Different MCA methods may require different types of weights derived in different ways. In the weights derivation process, the decision maker should be helped to understand the meaning and importance of his stated weights to increase the understanding and acceptance of the MCA with the decision maker. This understanding and acceptance is crucial for the applicability of the method.

10.1.2.3 Risk analysis

The term risk analysis as used in this report pertains to the evaluation of the total uncertainty associated with the various evaluation criteria. Traditional risk analysis is often referred to in economical or investment studies where a risk of a certain outcome is incorporated in the further calculations. However, risk analysis can also be a part of the sensitivity analysis performed as uncertainty evolving within various data, parameter, or impact assessments. This is the approach discussed in the following paragraphs.

A complete risk assessment procedure is likely to consist of the following five steps:

1. Identification of the risk that has to be analysed
2. A qualitative description of the problem and the risk – why it might occur, what you can do to reduce the risk, probability of the occurrence etc.
3. A quantitative analysis of the risk and the associated risk management options that is available to determine or find an optimal strategy for controlling and hereby solving the risk problem
4. Implementing the approved risk management strategy
5. Communicating the decision and its basis to various decision-makers.

The essence of the traditional risk analysis approach is to give the decision-maker a mean by which he can look ahead to the totality of any future outcome. The advantage of using any risk analysis approach is the possibility of differentiating the feature of risk information in terms of outcome criteria such as net present value (NPV), the internal rate of return (IRR), or the cost/benefit ratio (C/B ratio) by probability distributions.

Single point or deterministic modelling involves using a best guess estimate concerning each variable within the model to determine the actual outcome. Hereby, the uncertainty is performed on the model to determine how much such an outcome might vary from the point estimate calculated earlier. These variations are often referred to as “what if” scenarios where the advantage of using Risk Analysis (RA) is that instead of only creating a number of possible scenarios it effectively accounts for every possible value that each variable within the model can take by use of various continuous probability distributions. Each
variable/parameter assigned a probability distribution result in different scenarios that are weighted together by the probability of occurrence.

The main structure of a RA model is very similar to a deterministic single value rate of return model except that each variable in the RA model is represented by a probability distribution function. The objective is to calculate the combined impact of the variability and uncertainty in the models parameters in order to determine a total probability distribution of the model.

**Separation of uncertainty and variability**
The human striving of predicting a future outcome has been a wanted skill for many decades. Uncertainty and variability satisfies our inability to be able to precisely predict the future meaning that if we are able to determine these two components we would be able to predict the future outcome.

Sir David Cox defines the two concepts as: *variability is a phenomenon in the physical world to be measured, analysed and where appropriate explained. By contrast, uncertainty is an aspect of knowledge* (Vose 2002, pp 18).

Variability is the effect of a given chance and is a function of the given model system. This variable is the most difficult to explain as it is not possible to reduce by study or further measurements. However, it is possible to minimise the variability by changing the physical modelling system. One of the best known case examples of a variable experiment is the tossing of a coin. The normal prediction of a coin toss is a probability 50% for heads and 50% for tails. However, when making the experiment it is not possible to predict whether you achieve heads or tails in the next toss due to the coins inherent randomness.

It is therefore impossible to get a zero contribution from variability as designing any modelling systems. However, as mentioned earlier there are possibilities of controlling the variability by altering the whole modelling system.

Uncertainty is the modellers’ lack of knowledge concerning the parameters that characterise the modelling system (defined as the level of ignorance). This factor has the possibility of being reduced by further studies or measurements. Uncertainty is further by definition subjective since it is a function of the modellers’ level of knowledge; however, some techniques are available to allow a certain degree of objectiveness.

A schematically overview of the uncertainty concept are illustrated in Figure 10.2 (Salling and Leleur, 2006)
Intuitively, a separation of the two terms is not easy to comprehend as they both share exactly the same probability distributions looking and behaving identically. A reasonable assumption is therefore to create the same Monte Carlo model just dividing the different uncertain and variable parameters with different distributions. This is, however, likely to give wrongful information of the simulation, as the model outcome is represented in a resultant single distribution. This distribution represents the “best guess” distribution in terms of a composition between the uncertainty and the variability parameters. In this sense the interpretation of the modelling result is difficult due to the scaling of the vertical axis. This probability scale is a combination of both components resulting in ignorance in determination both of the inherent randomness of the system and what component is due to our ignorance of the same system (Salling, 2006).

One of the main advantages of separating the uncertainty and variability is that the total uncertainty of a model system does not show the actual source of the uncertainty. The information corresponding to the two sources implied in the total uncertainty is of great relevance towards the decision makers in a given situation. If a result shows that the level of uncertainty in a problem is huge this means that it is possible to collect further information and thereby reduce the level of uncertainty enabling us to improve our estimate. On the other hand, if the total uncertainty is nearly all due to variability it is proven to be a waste of time to collect further information and the only way to improve and thereby reduce the total uncertainty would be to change the whole modelling system.

10.2 Distributional impacts

Where will effects happen and who will experience the changes, are the two fundamental questions to be addressed in this section. The questions can be addressed using one model, but often two different models and/or methods must be used. The question of “who” can often be
addressed without a spatial disaggregation, but a disaggregation on types of individuals, households, industries, and vehicle types depending on which distribution is being addressed, is necessary. If we are looking at how different regions are affected we obviously need a spatial representation of the regions of interest.

Distribution is also about equity; is the costs and benefits spread in a way that is considered ‘fair’; it is about allocating resources between different generations – the concept of sustainability is relevant here.

10.2.1 Distributing CBA results spatially
Cost benefit analysis and to some extent also multi-criteria analysis are concerned with maximal efficiency and maximal socio-economic welfare for a nation, a region or the EU. There is no reference to who get the benefits and who pay the costs. From a policy point of view these are important and will in many decision processes play a central role. The socio-economic assessments thus have to be complemented with further analysis that can demonstrate these distributional issues. In many practical CBA, results are presented showing how different users of the transport system are affected. Examples are how road users, rail users, public transport users, etc., are affected; also, calculations showing the effects on users shifted between these groups of travellers are sometimes presented. These results are direct outputs from the transport models. However, this is only part of the issue; the interest is also related to the type of travellers. For example, the effect for singles with or without children, households with more individuals, the effects on different income groups, etc.

The distribution of impacts (spatially) can follow the normal evaluation procedures outlined above by doing separate CBA or MCA for each of the regions/groupes. EAI (2007) describes some methods that can be used to distribute the CBA effects. The EAI toolbox focuses on the value of costs and benefits with respect to income. In principle, decreasing marginal utility of income should be taken into account, as should the preferences of society for equity. The effect of not including these considerations can be that the overall effect of projects and policies on social welfare becomes unclear.

In practice, CBA can deal with distributional issues by incorporating distributional weights to costs and benefits for different income groups or instead by leaving out distributional issues from the analysis (implicitly applying equal weights to all impacts for all individuals) and instead deal with distributional issues in additional separate analyses.

Applying distributional weights might seem straightforward, but in practice it can be difficult to decide what exact weights to apply. Economic literature indicates that distributional weights that can take into account society’s distributional concerns could be derived through observations of, e.g., how the tax system is designed, how public spending is prioritised in practice, or to have the weights explicitly assigned by politicians. However, none of the suggestions seems to fully eliminate the associated problems. It is therefore reasonable to ask whether CBA can realistically be expected to incorporate distributional issues in practice, especially since the use of different weights can potentially lead to widely different results of the analysis.
This is problematic since distributional considerations can be an important criterion for decision makers alongside efficiency considerations. As a supplement to CBA, the distributional consequences of a project or policy should therefore be analysed in separate analyses. Such a supplement to a CBA will contribute to a more informed decision base. The trade-off between efficiency and equity becomes more significant when CBA is performed on a supranational level, as for example in a European Union context. This is the case both due to differences in income levels and due to a limited existence of redistribution mechanisms in this context.

In the socio-economic assessment of the Fehmarn Belt fixed link between Denmark and Germany, it was discussed whether the project should be evaluated on a total basis including all costs and benefits (the traditional CBA). This was of interest in order to determine a distribution of the financing of the project. If all benefits fall in one of the countries, the other country would then hesitate in paying, e.g., half of the construction costs. So it was decided to do a complete CBA, a CBA covering only Denmark and Germany, and two national CBA for each of Denmark and Germany based on an initial agreement of how construction costs should be distributed.

Undertaking a separate CBA for all regions/countries is not feasible in all cases. The Fehmarn Belt case is a major project with a large budget for both the planning process and the implementation process. In such major projects the disaggregate CBA is feasible, but in smaller projects we need to consider other approaches to analyse how effects and costs are distributed. Some options are presented in the following section.

10.2.2 Model approaches to differentiation of economic costs and benefits

Economic models can often be used to investigate distribution effects because they include different types of individuals (households, persons, types of companies, etc.). If the models are spatial, they can further provide answers to the spatial distribution effects from some exogenous change.

A number of economic models that can be applied to illustrate distribution effects are described in Chapter 8. The typical models used to assess differentiation of economic effects are the (spatial) input-output models, the production function approach, and (spatial) computable general equilibrium models (SCGE). The capability of the model in this context depends on how it is related to the transport models if, as an example, the question is: distribution effects from a new major infrastructure investment. In such a case, it is crucial to have precise calculations of the changes in transport demand, divided on regions, households, etc. The link to transport models is not always necessary to analyse distribution effects from economic measures such as road pricing. However, the quality of the results and the range of effects that can be included are obviously depending on the integration of the economic model with the transport model(s).

A few examples showing the distribution effects from road pricing for trucks are known. Doll and Schaffer (2007) use an input-output model to calculate the effects from the German heavy vehicle fee on different industries in Germany. The distribution effects from truck road pricing come through trade between industries in different regions. This diffuses the effect from the original source (the transport industry) to the users of transport. The distribution of
price changes caused by the vehicle fees found by Doll and Schaffer (2007) are illustrated in Table 10.5 for the ten most affected industries in Germany.

The effects from passenger road pricing transpire from the private costs of transport to the individual choice of mode, location, work place and labour supply.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Min (%)</th>
<th>Max (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road transport</td>
<td>4.35</td>
<td>5.77</td>
</tr>
<tr>
<td>Wood and wood products</td>
<td>0.15</td>
<td>0.2</td>
</tr>
<tr>
<td>Ceramics and building materials</td>
<td>0.13</td>
<td>0.17</td>
</tr>
<tr>
<td>Tobacco</td>
<td>0.1</td>
<td>0.13</td>
</tr>
<tr>
<td>Paper and paper products</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>Chemical pulp</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>Forestry</td>
<td>0.08</td>
<td>0.11</td>
</tr>
<tr>
<td>Food and animal feed</td>
<td>0.08</td>
<td>0.1</td>
</tr>
<tr>
<td>Beverages</td>
<td>0.08</td>
<td>0.1</td>
</tr>
<tr>
<td>Construction services</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>Whole economy</td>
<td>0.09</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Table 10.5: Price effects by selected industries, Germany, 2002

Source: Doll and Schaffer (2007)

The LUTI (land-us/transport interaction) type models (Chapter 7) is another approach that can illustrate where effects will happen. An advantage in these models is that they highlight spatial changes that are not included in pure economic or pure transport models. The potential urban and/or job creation effects as consequences of changes in the transport network can be significant and is not covered entirely in the pure models. However, this is only true to some extent. LUTI models cannot illustrate the differentiation of welfare effects. LUTI models provide mainly information about physical changes in land use and in the transportation network.

(S)CGE models are very often used for welfare evaluations. The aim of these models is often to demonstrate the welfare implications of policy changes. A welfare function is formulated to do this. This function is found as the sum over individual changes in welfare:

\[ \sum_{i,r} \Delta Welfare_{i,r}, \]

where \( i \) denotes the individual agents (households, firms, etc.), and \( r \) the spatial resolution of the model.

The changes are calculated as equilibrium values between supply and demand in all sectors, regions, and households (see Chapter 8 for more about these models and how they are solved). So SCGE models are not only a strong tool that can be used to assess the so-called wider economic benefits, they can immediately be used to show the differentiation and distribution of results. It is possible to define the welfare function such that effects on
different types of individuals are weighed according to some predefined scale. However, this is seldom used because the choice of weight is controversial.

10.2.3 Infrastructure and equality (equity)

Income equality is addressed in the economic literature through a large number of scientific articles and empirical analysis. The analysis investigates the distribution of income between rich and poor income groups in countries, between countries, and regions. The analysis is not concerned with the changes for specific groups, but is a calculation of the aggregate “equity” of the analysed area, region, or country. As such, this approach cannot be used to say anything about the distribution of impacts from, e.g., infrastructure investments. However, it is possible to use equity measures such as the Gini-coefficient to show how infrastructure investments and transport taxes influence general equity. Some of the examples of this are Yamano and Ohkawara (2000), Sumalee (2003). Sumalee adopts the Gini coefficient, which is invented for measuring income distribution, to measure the spatial equity impact of a toll-ring.

It is often found that equity and efficiency are in-complementary objectives. Maximal efficiency is obtained at the cost of equity and also the other way around. Scully (2002) and Bruno et al. (1999) use empirical analysis to illustrate the trade-off, which is addressed in a theoretical model by Varian (1974).

Yamano and Ohkawara (2000) clearly demonstrate the trade-off related to public investments (including transport investments). They use a production function approach where separate functions for different regions are applied. They estimate how output changes due to investments (not only transport investments, but public investments in general). They further analyse the trade-off between efficiency and equity using income per capita and GDP measures also at the regional level. Using data for Japan, they find that productivity in depressed regions is lower than in well-functioning regions. This implies that investments in order to achieve even regional growth lead to lower general output (lower efficiency).

Emission taxes are often advocated on the grounds of efficiency. West (2005) uses a partial equilibrium model to investigate the equity implications on different income groups from emission taxes. Emission taxes make transport more expensive. West finds that low income groups are more responsive to higher costs and thus reduce their miles driven more than higher income groups. However, the vehicle ownership is lower for low income groups, which implies that the impact is somewhat mitigated. West’s results show that poor people face a heavier burden from the environmental taxes because they drive more miles relative to their income than rich people. This is especially true if the tax is progressive so that more polluting vehicles pay a higher tax.

West’s analysis is based on the relative welfare changes (changes in consumers’ surplus). This is also the recommended approach in the literature, but West only does it in a partial equilibrium model. Obviously a partial approach only takes into account parts of the impacts. The effect from the revenues raised is for example not included, neither is the effect from reductions in emissions that may harm low income groups relatively more. Other studies focus solely on how income is affected in different groups. This may in many cases correspond to the consumers’ surplus if averages values of time are used, also because the consumers’ surplus measure does not take the income effect into account.
10.2.4 Distribution between generations

The Brundtland Commission defines sustainable development as: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. With this definition (environmental) sustainability is an issue of equity between generations. An example of this choice between generations is Hartwick (1977), who analyses current consumption of exhaustible resources versus the consumption of future generations. This is also the problem addressed by Solow (1974).

Most transport infrastructure has a long operation period. Investments today will thus have an impact on the future generations. Not only will future generations benefit from investments in infrastructure today, but current investments will be financed in ways that involves the payment (e.g., through taxes) of future generations and infrastructure use natural resources that cannot be used for other purposes in the future; the urban development is closely related to infrastructure as discussed in Chapter 7 about land-use models. The discussion about how effects are distributed across generations is very relevant for transport projects.

In CBA, a discount rate is used to evaluate future costs and benefits as they are perceived today. However, the discounting of costs and benefits, which is a fundamental part of the CBA, disregards the desires and needs of future generations, hence compromising intergenerational equity.

Costs that are more than thirty years away become almost valueless when discounting at normal rates. Hence, long-term costs, such as, e.g., environmental resource depletion may be effectively ignored in a CBA. Discounting therefore discriminates against future generations by saying that future costs are worth less than present costs, and that present benefits are worth more than future benefits.

The logic behind discounting derives from the logic of money – that a person would prefer to receive money now than the same amount in the future (the time preference rate is positive). This is because:

1. Money obtained now can be invested and earn interest
2. People tend to be impatient (they want to enjoy benefits sooner and costs later)
3. The person might die before he or she gets the money
4. One cannot be sure of getting the money in the future
5. People in the future will probably be better off; money will not be worth as much then

Seen from society’s point of view, it is more the number and types of individuals receiving a given benefit that matters and not whether it is a specific person. Hence, the idea that someone would like to consume now rather than in the future is not applicable to public goods, which can be enjoyed now and in the future. Also, the risk of one person dying before he or she gets the benefit is of no relevance if this person is just “exchanged” by another (as will be the case for a number of costs or benefit elements accruing over time). Any positive discount rate devalues future costs or benefits and this disadvantages future generations with respect to today’s decisions. The logic of money – and in this respect the logic of discounting
may thus seem inappropriate when evaluating certain types of costs and benefits. This is especially the case for (long term) environmental impacts.

### 10.3 Sustainable transport goals

Sustainable development is adopted as an important overall policy objective at all levels and sustainable transport or sustainable mobility is the corresponding overarching objective in the transport sector:

- In the introductory part on policy guidelines in the White Paper on European transport policy (EC, 2001) it is stated: “A modern transport system must be sustainable from an economic and social as well as an environmental viewpoint”. A key aim is to decouple the strong historical link between economic growth and mobility by integrated pricing, revitalising of alternative modes, and targeted investment in the trans-European network. In the mid-term review of the White Paper, the title is “Keep Europe moving – Sustainable mobility for our continent” and in the very first sentence it is stated: “The objective of an EU sustainable transport policy is that our transport systems meet society’s economic, social, and environmental needs”. Transport systems should provide mobility for European competitiveness and cohesion while protecting the environment (EC, 2006).
- The Swedish transport policy may serve as an example on the national level. Under the title “Transport policy for sustainable development” the main objective reads: “The overall policy objective is to ensure that citizens and businesses in all parts of the country are provided with transport that is efficient in terms of the economy as a whole and sustainable in the long term”. The overall transport policy objective is broken down into six sub-goals (Swedish Government, 1998).
- Very similar formulations can be found at the regional level. In the Regional Development Plan 2001 for the Stockholm region, a vision of long-term sustainable development with social and economic balance constituted the starting point. The vision relied on three basic objectives: international competitiveness, good and equal living conditions, and a long-term sustainable living environment (Stockholm County Council, 2003).

Planning principles and planning methods for a sustainable development of spatial systems and for achieving sustainable mobility have been subject to much research and practical testing. A few examples are mentioned here:

All these research efforts try to assess sustainable development with various indicator systems and either combine these indicators into an overall objective or explicitly work with multiple objectives. As an example, PROPOLIS defined a system of eight environmental indicators (covering the sub-themes Global climate change, Air pollution, Consumption of natural resources, Environmental quality), nineteen social indicators (covering the sub-themes Health, Equity, Opportunities, Accessibility and traffic) and eight economic indicators (components of Total net benefits from transport). The impacts of policies in terms of these individual indicators were assessed and the result was aggregated (by applying weights) to each of the main three sustainability dimensions. Then a multi-criteria evaluation is conducted in order to find policies with a well-balanced and favourable sustainability profile.

The PROPOLIS impact analysis is biased towards direct transport policy impacts on environmental, social, and economic indicators, leaving out the indirect impacts through, e.g., land-use changes. Other transport related indicator systems are provided by, e.g., The Transport and Environment Reporting Mechanism (TERM) within the European Environmental Agency (about 40 indicators, environmental focus; EEA, 2001) and Sustainable Transportation Performance Indicators (STPI) within the Centre for Sustainable Transportation in Canada (initially 14 indicators with about 30 additional proposals; CST, 2002).
11 Impact models

Impact models refer to models for external effects, which are indirectly derived from transport demand. Due to Newberry (1990), the following effects may be considered;

- Road damage costs (including maintenance cost and road wear)
- Traffic noise
- Local emissions
- Global emissions (including climate effects)
- Accidents
- Barrier effects

Although congestion is often considered as an external effect, the modelling of congestion is most often an integrated part of traffic models. In other words, congestion should be considered as part of the assignment-modelling framework described in Chapter 9, rather than an external effect. The implementation of impact models requires two elements.

1. Models that relate transport demand with environmental impacts
2. Factors that converts changes in environmental impacts to monetary units suitable for cost-benefit analysis

With respect to the second requirement, it is common practise to establish a national manual that includes all monetary conversion factors for the different external effects. An example can be seen in Danish Ministry of Transport and Energy (2006).

11.1 Linking output of transport models to impact models

A first and important step in impact modelling is the linkage to transport models. Generally, a number of specialised fields exist in which the results of transport models are used, these are environmental studies, cost benefit analysis, etc.

For each application the need for information differs, however as a rule, the output of a transport model needs some adjustment to be used as an input for an impact study. The following adjustments are common examples are:

- For environmental studies (e.g., air quality studies) the output for an average workday needs to be transformed towards an average weekday.
- For Cost Benefit Analysis the results of travel time savings per work day needs to be aggregated to an annual basis.
- If the data are related to passengers, a conversion from passenger to the number of cars is needed. This ratio may differ significantly between trip purpose and may involve significant trends over time, e.g., accounting for the fact that a higher proportion of the population is becoming middle income single households.
- If the data do not include any subdivision of cars, it may be necessary to account for lorries and trucks, which pollute more and produce more congestion per vehicle. In addition, if there is a certain proportion of the car stock that consists of
diesel vehicles, this may be considered in that these cars will produce less emission.

11.2 Environmental impact studies

By applying monetary values to impacts, the total costs of the various impacts can be estimated. This is relevant because it gives an idea of the relative importance of the different impacts, e.g., it indicates what is important and should definitely be included in a cost-benefit analysis, and what is probably less important and may be skipped. However, setting up a complete ranking may be very difficult due to large structural differences from city to city and country to country. Instead, we will briefly consider the literature.

In a study by the Danish Environmental Protection Agency (DEPA, 2002), total external traffic costs for Denmark were estimated to 4.4 billion euros. According to the study more than 50% of all external effects were due to accidents, whereas climate effects and local emissions accounted for approximately 30% and noise for 8%. Congestion was estimated to less than 6%, which, however, seems to be in opposition to more recent studies. In a congestion study from 2004 (Nielsen and Landex, 2004) congestion costs in the Copenhagen region alone were estimated to 0.8 billion euros. International studies seem to indicate that among the various effects, accidents are the most important. Edlin and Karaca-Mandin (2006) estimated the Pigovian tax for internalisation of accidents externalities to $66 billion in California, which at present is more than the collected state taxes. The direct measurable costs due to accidents in EU15 are estimated to 45 billion euros of the European commission (EC, 2001). However, according to the Road Safety Action Program (EC, 2003) indirect costs of accidents may be as high as 160 billion euros. In a recent cost-benefit analysis of road charging schemes in Copenhagen (Rich and Nielsen, 2006) the importance of accidents was confirmed. However, traffic noise was the second largest external effect with emissions being the third most important effect. For emissions, the impacts from local emissions were slightly higher than for the global emissions. Studies of the charging systems in London and Stockholm indicate that emissions are significant, whereas noise is less significant.

11.3 Models for environmental impacts

Generally, the different external effects can be divided in local and global effects. The locale effects are effects that will impact the local community, e.g., noise, local emissions, and barrier effects. The global effect, on the other hand, only influence the society in global terms, e.g., CO2 effect and climate effects. The distinction between these terms is important for two reasons. Firstly, they count very differently politically. The global effects are of concern for national politicians, whereas local effects are of concern to local politicians. Secondly, because the price of these effects is determined in different markets, e.g. a world market for CO2 and a local marked for impacts.

37 The calculation of congestion was for the whole country including very rural parts with no congestion. Moreover, congestion costs was based on a German speed-flow relation from 1997, which makes it somewhat uncertain compared to more recent studies.
11.3.1 Transport safety
When applied in specific analyses, the accident costs appear as a total accident cost corresponding to a statistical average of types of accidents. In Denmark both are categorised as:

- An average accident reported to police.
- An average accident with personal injury reported to the police.

To determine the number of accidents the Danish road directorate has develop a method based on road type. The method divides the accidents into two categories (Hemdorff and Greibe, 2001; Greibe, 2003):

- Accidents in intersections
- Accidents on free stretches between intersections

The accident frequency on each road link and in each intersection is calculated based on a Poisson regression segmented on road type.

For intersections, the following formula is used for the regression:

$$ A_{\text{Intersections}} = a \cdot N_{\text{pri}}^{p1} \cdot N_{\text{sec}}^{p2}, $$

where:

- $A_{\text{Intersections}}$ is the number of accidents in the intersection each year
- $N_{\text{pri}}$ is the Average Daily Traffic on the primarily road in the intersection
- $N_{\text{sec}}$ is the Average Daily Traffic on the secondarily road in the intersection
- $a$, $p1$, and $p2$ are constants depending on the type of intersection

For free stretches between intersections the formula used is:

$$ A_{\text{Stretches}} = a \cdot N^p, $$

where:

- $A_{\text{Stretches}}$ is the number of accidents each year per kilometer road
- $N$ is the average daily traffic on the road
- $a$ and $p$ are constants depending on the road type

More advanced models may be implemented if data are available. Vistisen D. (2002) considers statistical models for black-spot identification, whereas Jones and Jørgensen (2003) and Madsen (2006) consider how to simultaneously estimate the number of accidents and the fatality of the accidents.

11.3.2 Maintenance
The Danish method for calculating maintenance costs use a decomposition into three cost components:
Ordinary maintenance comprising repair of pavements, maintenance of shoulders, etc., and traffic control and safety measures;

Winter maintenance comprising snow clearing, spreading of gravel, and deciding salt, etc.

Other maintenance including road lighting, extra costs due to frost damage, and other operation costs

The Danish model for estimating the maintenance costs is based on analysing previous expenditures. From this a formula describing a relationship between some road type dependent variables, the width of the road and the average daily traffic has been developed (Leleur, 2000):

\[ M = (D_1 + D_2 \cdot AADT) \cdot (0.65 + D_3 \cdot WL) \]

where:

- \( D_1, D_2 \) and \( D_3 \) are constants dependent on road type – motorway or not-motorway type
- \( AADT \) is the Average Daily Traffic
- \( WL \) is the total width of lanes measured in meters

An alternative approach is to set maintenance cost to a fixed percentage of the construction cost. This is a favourable approach when more complicated infrastructure projects need to be assessed. However, an assessment of the validity of this approach needs to be considered.

### 11.3.3 Traffic noise

Noise and air pollution are the two environmental impacts most often considered within an evaluation of a road project.

Although it has been a public concern in the debate about roads and environment for at least three decades, measurement of noise levels and investigation of the people exposed is far from comprehensive. An estimate shows that about 110 million people in the industrial world are exposed to road traffic noise levels above 65 dB(A). This is a threshold level considered as unacceptable in OECD countries (Leleur, 2000, p. 113).

Noise impact assessment is typically carried out as a two-step procedure. For example, the procedure in Denmark and Sweden is as follows. Step 1 consists of a noise measurement, or less costly (in case of small road projects) of a model prediction based on model parameters including traffic flow and vehicle speed. The results for a certain road stretch are presented as a noise contour map indicating dB(A)-zones with a certain noise level. Step 2 comprises the translation of these noise levels into annoyance by multiplication of the annoyance level associated to each dB(A)-zone with the number of people or dwellings affected. In general, annoyance level is doubled for each 5 or 10 dB(A) increase.

The net change in noise annoyance is calculated by use of an index measured in NAI (noise annoyance index) units. The index is computed by summing the number of dwellings in noise zones, each with a different noise level. Before summation, the number of dwellings is multiplied with a nuisance factor, see Table 11.1 (Leleur, 2000).
Table 11.1: Danish noise model parameters

The nuisance factor of the model is estimated on the basis of household interviews.

Given traffic flows and the average speeds for cars and trucks as well as the road surroundings it is possible to calculate the noise in different distances from the road centre. The method used in Denmark is the Nordic Prediction method (Bendtsen, 1999). The method first calculates the basic noise level for the road. Afterwards the basic noise level is corrected according to the distance from the road centre to receiver. The correction depends on the surroundings for the road (e.g., noise barriers along the street, high houses where the noise is reflected back and forth, or soft vegetation where the sound is absorbed).

The noise level model, used to determine the noise contour (iso-decibel) lines applies the following parameters:

- Traffic volume
- Speed and proportion of lorries
- Distance to middle of road
- Surface of physical surroundings
- Noise protection (if any)

The NAI index is calculated as (Leleur, 2000, p. 131):

\[ NAI = 0.11 \cdot B_A + 0.22 \cdot B_B + 0.45 \cdot B_C + 0.93 \cdot B_D + 1.92 \cdot B_E. \]

The net change, \( \Delta NAI \), is found by subtracting \( NAI_{after} \) from \( NAI_{before}. \) The unit price per NAI unit is based on the hedonic pricing method.

When the basic noise level is determined the number of households affected by the noise can be examined by GIS analysis (refer to Figure 11.2). One way is to calculate noise in points along the road in different distances. These points can either be interpolated into polygons or used as raster layers to make analysis on the number of affected households. A problem with this method can be the computing time for the noise prediction, especially if the noise levels are examined three-dimensionally for a huge model area. A more feasible solution in many cases therefore is to use simple buffer analysis. Based on the basic noise level the distance to each critical noise contour given in Table 11.1 can be determined. Buffers can then be applied on the road links (according to these distances) and the number of affected households within the buffers can be examined. An example of this last approach can be found in a study on the effects of road pricing in Copenhagen (Wrang et al. 2006; Rich and Nielsen, 2006; 2007).
11.3.4 Emissions

For air pollution from road traffic, it is common to make a distinction between local pollution, made up mainly of carbon monoxide (CO) and nitrogen dioxide (NO\textsubscript{x}), and the non-local carbon dioxide (CO\textsubscript{2}) pollution, which contributes to the global greenhouse effect. Other pollutants also occur, like fuel additive emissions, particulate matters, sulfur dioxide (SO\textsubscript{2}) and volatile organic compounds such as hydrocarbons (HC). Determination of the air quality can be carried out by direct emission measurements or at lesser costs by use of prediction models.

The adverse effects from air pollution (and noise) are widely recognised, as are the detrimental effects from air pollution to the natural environment (acid rain and climatic changes). However, prediction of the impacts is a particular complicated question due to consequences that are irreversible and accumulative.

Air quality improvement can be achieved by conforming emission limits to air quality standards, while long-term, non-local effects can be met by setting overall emission reductions to be obtained in a target year.

Air pollution is determined as a local (emission) and a regional (emission) effect. The local effect depends on the surroundings, which, by means of the land-use weights in Table 11.2 (Leleur, 2000, p. 131), are used to estimate the number of people exposed to the pollution.

<table>
<thead>
<tr>
<th>Surroundings</th>
<th>Land-use weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shops, public offices, schools, apartment buildings</td>
<td>1.0</td>
</tr>
<tr>
<td>Low rise housing</td>
<td>0.4</td>
</tr>
<tr>
<td>Summer houses</td>
<td>0.2</td>
</tr>
<tr>
<td>Recreational city areas</td>
<td>0.2</td>
</tr>
<tr>
<td>Industrial areas</td>
<td>0.0</td>
</tr>
<tr>
<td>Unbuilt areas</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 11.2: Land-use weights in Danish air pollution model

The effect of local air pollution has been assessed to be negligible for AADT ≤ 4000 and for this reason calculations are carried out only for network sections with a higher traffic volume, N. For these sections, the amount of travel above the threshold is calculated for each section of length L, and the annual contribution 365(N-4000)L is adjusted by multiplying it with a factor determined by adding the land-use weight from each side of the road section. This local component of air pollution nuisance (LBT) is calculated for the before and after situation and the net change is determined.

The regional component of LBT is found as the net change of vehicle kilometres travelled, and is added to the local component, whereby ΔLBT is determined.

The unit price for private cars is estimated using an avoidance cost approach based on the price of catalytic converters. For lorries, the costs are related to the amount of NO\textsubscript{x} emitted per kilometer compared with the emissions from a private car. Based on this, lorries are given a triple weight compared with private cars per km travelled. An example of the price
discrimination of local emissions and their distribution on fuel type is presented in Table 11.3 below.

<table>
<thead>
<tr>
<th></th>
<th>Copenhagen centre</th>
<th>Frederiksberg</th>
<th>Copenhagen County</th>
<th>Frederiksborg County</th>
<th>Roskilde County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lorries</td>
<td>0.064</td>
<td>0.064</td>
<td>0.027</td>
<td>0.027</td>
<td>0.027</td>
</tr>
<tr>
<td>Vans diesel</td>
<td>0.025</td>
<td>0.025</td>
<td>0.013</td>
<td>0.013</td>
<td>0.013</td>
</tr>
<tr>
<td>Vans gas</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>Cars diesel</td>
<td>0.011</td>
<td>0.011</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Cars gas</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
</tbody>
</table>

**Tabel 11.3: Valuation of local emissions, Euro cents pr. km**

Source: Wrang et al. (2006)

### 11.3.5 Barrier effects

This effect is a measure of the hindrance of movement and the risk perceived from a nearby traffic stream. The index BRBT (severance and perceived risk) for the effect is based on:

- Need for crossing
- Traffic volume
- Speed
- Proportion of lorries
- Number of controlled intersections
- Presence of footpaths and cycle paths

A system similar to the land-use weights applied for estimation of local air pollution has been developed to estimate the demand for crossing and walking along the road. This demand, which is highest for shopping streets and urban centres, is multiplied by a barrier and risk perception factor derived from the parameters mentioned above.

The BRBT index is calculated in the before and after situation, whereby \( \Delta BRBT \) is obtained. The current valuation method for the unit price of BRBT is found by relating it to the valuation of NAI for noise. Hence, if \( k \) projects in a pool is considered:

\[
\Delta BRBT = \frac{1}{2} \Delta NAI.
\]

This is reminiscent of a previous valuation principle where index values for noise, barrier effect and risk perception, and air pollution were determined to be 60 %, 30 %, and 10 % of the benefits for the remaining traffic economic effects.

### 11.4 Valuation of environmental effects

The valuation principles for environmental impacts are based on concepts such as damage cost and control cost (Leleur, 2000). The damage cost include the total costs caused by a level of pollution, while the control cost is made up of the costs that are necessary to neutralise or remove the pollution, e.g., with traffic noise the expenses for noise shields and double glasing would be control costs. The control cost is also sometimes referred to as the reduction cost or the avoidance cost.
The optimal level of pollution, taking a strict economic approach, is determined by the minimum of the total cost resulting from the damage and control cost, added together as indicated by $E$ to the left in Figure 11.1 (Leleur, 2000, pp 114). This level is determined as shown in the figure to the right, where the marginal control cost equals the marginal damage cost.

The above approach, which belongs to the third of the previously described valuation principles, can only be indicative. First, the necessary curves are very difficult to estimate. Second, avoiding, for example, indoor noise gives only a minimum value of the noise improvement. This assumes also that the technology for making noise shields and double-glassing is cost-efficient for the problem at hand. For air pollution, cost-efficient technology is apparently available as unleaded petrol and catalytic converters are in general use for removing some of the pollutants. This is not the case, however, for carbon dioxide as electric cars are not in great demand due to battery technology. Cost-efficiency with regard to technology cannot be judged in isolation, but is a reflection of the societal strategies adopted and developed to cope with the pollution problem (Leleur, 2000).

The following methods belonging to the second category of valuation principles are also used for environmental valuation. They are the travel cost method (TCM), hedonic pricing method (HPM) and contingent valuation method (CVM) (Leleur, 2000):

- The TCM uses market related prices to estimate the demand curve for a non-market good. For example, the type of information that is used when comparing a recreation area 1, a distance $a_1$ away, with an area 2 with travel distance $a_2$, is the difference in travel cost with $a_1 > a_2$. The recreative value of area 1, when chosen instead of area 2, must be at least equal to the extra travel cost. TCM in fact has been applied especially to this type of environmental valuation situation.
The HPM uses information from actual market decisions to obtain the value for non-market goods. HPM in transport planning has been used especially to valuate (the absence of) noise. The price for a house in a silent area is compared with a house of similar type and quality in an area with traffic noise. In so far there are no other differences; the difference in price is an indirect valuation of the noise annoyance.

The CVM is a stated preference method applied on non-market goods. In a structured way, people are asked about their willingness to pay for an environmental gain or their willingness-to-accept for an environmental loss. CVM is attractive from a theoretical point of view because it comprises both a use-value and a so-called option value, which is the value, assessed by a person with future use possibilities in mind. The revealed preference technique can necessarily only elicit the use-values, which is but a part of the total value.

The three described methods have their advantages and shortcomings. TCM and HPM are prone to statistical estimation problems but both are based on choices carried out on the basis of real market prices, whereas CVM assumes a hypothetical market. On the other hand, CVM attempts to capture option values and must be seen as a promising technique. Much work has already been done to cope with various types of bias in the interview situation, but CVM should be further developed, while incorporating, among other things, more knowledge from disciplines such as social psychology (Leleur, 2000).

11.4.1 Accidents
The methodology commonly used for valuing traffic accidents is a composite of different tentative principles. This is understandable because accidents, in the eyes of many people, are “beyond” economic theory. Valuation efforts in this respect, however, could be seen from the point of view that explicit accounts may serve to strengthen planning efforts to increase transport safety.

If an accident is split into a material side and a personal side, the material side costs (damaged cars, expenses for ambulance, police, and medical treatment) can be estimated as actual costs. Assessing the personal side is more complicated. The common approach, known as the human capital method, starts by making an estimate of the production loss and a contribution to cover pain, grief, and suffering resulting from the accident. This contribution is political determined. In Denmark, it is seen as expressing a societal interest in avoiding accidents (Leleur, 2000, pp 112). The welfare loss accounts on the average for approximately 25 % of the total costs per person seriously injured, but increases to 67 % of the total costs per person killed in a fatal accident (Clausen et al., 1991).

Objections have been raised to the human capital method, because it seems irrelevant to evaluate safety on the basis of current and future income levels and production losses. Instead, the issues that should be addressed are the individual person’s risk aversion and his willingness to pay (WTP) for a risk reduction for a prospective accident. By adding the WTP

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38 The discrete choice methods described in Chapter 4 can in many cases supplement CVM.
amounts for those affected by a certain safety improvement – to be estimated by use of revealed and stated preference technique – an overall value is obtained. However, there are methodological and practical problems connected to adopting WTP principles. One consequence is significant increases in value estimates (Leleur, 2000).

In a European comparison the English, Finnish (also WTP-based), and the Swedish values (explicitly added a welfare loss as the Danish estimate) top the list for the value of a saved life by avoiding a fatal accident. The values for accidents with serious injuries and slight injuries to various extend incorporate WTP-based principles.

11.4.2 Traffic noise
Methodologically, there has been two main approaches to the valuation of noise; revealed preference (RP) and stated preference (SP). In the revealed preference approach, valuation is based on actually observed market behaviour, whereas in stated preference methods, people are asked hypothetical questions in order to replicate a real-world market situation. Among RP based techniques only the HPM (Rosen, 1974) has been successful in the valuation of noise. Other methods, such as the TCM or the averting behaviour approach, are inappropriate for a number of reasons (Vainio and Paque, 2001). The SP approach to non-market valuation has been called contingent valuation (CV). Generally, CV studies can be quite different in their SP design and in the way data are interpreted.

The European Commission initiated in 2001 (Vainio and Paque, 2001) a workshop on “State-of-the-art in noise valuation” to review current best estimates for monetary valuation of noise and to identify research needs. The final report (Navrud, 2002) presented a comprehensive literature review and concluded that SP methods, with separate levels for different annoyance levels, were the preferable method. However, some of the problems of the HPM can be dealt with by introducing more sophisticated models (Rich and Nielsen, 2006).

11.5 GIS and impacts models
Depending on the available data, geographical information systems can useful in both determining impacts and interpreting results. For traffic noise impact, a GIS buffer analysis or GIS raster analysis can be useful as a tool to determine how many households are affected by noise. A general illustration of transport and the assessment of external effects may be used as shown in Figure 11.2 below.
The GIS links a background map with a transport network. Subsequently this can be linked with other layers related to the building mass or noise buffer maps in order to estimate the number of people exposed within certain buffers.

GIS overlay analyses are often used in determining impacts when information on road type and about surroundings are limited for each link in the network. By using the road link spatial location and combining it with other digital maps, missing information can be joined to the network. An example of this type of analysis could be to classify the roads depending on the surroundings with the use of land-use maps.
11.6 Forecasting

Generally, external effects can be considered as being derived from transport activities. This means that impact models are modelled after the transport model has reached equilibrium and can be considered as an “add-on” tool. However, some factors may affect the forecasting of impacts.

- Introduction of new technology: Improved filters and catalytic converters may reduce emissions and ITS may reduce accidents.
- Changes of legislative basis: Reduced speed limits and changes of the range of punishment may affect accidents and noise.
- Behavioural issues: There may be behavioural changes that are not easily factored into the traffic models.
- Taxation policies: May promote different driving patterns that, however, should be reflected in the traffic models.

Whenever possible, trends may be detected and then filtered out from the impact models.
12 Linking of scales and aggregation

This chapter discusses scaling of models. Before elaborating on scales and linking of scales, the adoption of level of detail is discussed in Section 12.1. The choice of spatial resolution is a conflict between accuracy, objectives, and cost facing the modeller in an early stage of model development.

Most models are developed with one scale in mind, e.g., international, national or regional travel. In Section 12.2, models are typified into decision level and the different scales of modelling are briefly discussed with inclusion of few examples. Mixing and linking of models with different scales, e.g., regional and national models could potentially be a cost efficient way to incorporate the advantages from the different scales and improve modelling capabilities. In practice, however, it is often complicated and prevented by some inherent differences in the models. Further issues about linking of scales and problems are discussed in Section 12.3.

12.1 Space and objectives

The modeller has an early choice of coverage and spatial resolution to match the objectives. If, for instance, the scheme to be tested includes effects on international flows of passenger and freight caused by major changes in cost structures and infrastructure, the model must be scaled to at least European level.

In principle, greater accuracy can be achieved by using a more detailed zoning system. To take advantage of the fine spatial resolution, however, accurate and consistent data need to be available at the fine spatial resolution. When data (OD pattern, population, employment, income, etc.) have to be approximated to match the fine zonal system, the achievements of a fine spatial resolution is doubtful. To achieve the same accuracy in the description of an OD pattern the sample size requirements increase by number of zones, therefore, it also reflects a conflict between accuracy and cost. In practice, it is often professional judgement to choose a zonal system that considers requirements for accuracy in network flows, computing time, and data constraints necessary to meet the objectives of the study.

Depending on the scales of modelling, few simple guidelines for spatial resolution are available. In models at global level, a zoning system based on countries or even aggregates of countries should be sufficient. Models at European level are often based on NUTS 2 or NUTS 3 since accurate network flows seldom are the primarily objective. While national models often are based on administrative divisions or subdivisions, e.g., municipalities, the zonal system of regional, and local models usually requires a much finer zonal system to estimate network flows and congestion effects accurately.

If the model focuses on a smaller area within the study area, which is often the case, then different levels of spatial resolution are needed. This is, for instance, the case in corridor models, where focus is on traffic in the corridor or along the screen line. Thus, a fine zonal system could be defined in and around the centre of interest and decreased in detail by distance to the centre of the model.
12.2 Scaling of models

Section 3.2 introduced a classification of transport models by scale of decision level:

- Global models
- European level models
- National model
- Regional models
- Metropolitan and urban models
- Corridor models

Below we discuss some of the different levels of scales in passenger, freight, and economic models and provide some examples.

12.2.1 Global models

Transport at the global level is mainly concerned with the movement of goods—freight transport, but also to some extent international business and tourism using international air transport. A very large part of the goods consumed in the EU member states comes from overseas (Asia and North America). The trade relations with the overseas regions have a very specific impact on port regions, either the seaports, where, e.g., containers arrive directly or the main corridors, where the goods are transported to and from the global container ports in Germany, Benelux, Greece, Spain or Italy. Individual countries or regions do therefore have an interest in the volumes of international (global) trade in order to anticipate the need for future infrastructure channels towards the global market. Normally this is not exercises that are undertaken by individual countries. It has been the topic of the TEN-STAC project financed by the European Commission (NEA, 2003). Global models are not detailed and they usually provide forecasts only at a national level.

Many exogenous assumptions concerning economy and technology (e.g., vehicle technology) are strongly related to global developments. The global economy, the global technology context, the global environment, and global social conditions are interrelated. They affect both European, national, and regional developments. Economic growth, job location, prices on vehicles, and energy and technological improvements in terms of emission reductions, energy efficiency and safety constitute important inputs to transport modelling. Technical standards and socio-economic prerequisites for national and regional transport developments are increasingly linked to or determined in global contexts (global markets, international institutions, etc.).

12.2.2 European-level models

Through-traffic is an important issue in many countries. International traffic is similarly very important, especially concerning freight traffic. In border regions, for instance, traffic derives from local, regional as well as national and international contexts. In addition, the choice of access modes to airports and train stations is important in regions where major airports are located.
In national or regional models, international transport is often treated by external zones. The usual practice is to estimate international freight and passenger transport exogenously to the model and distribute it among the internal zones of the model. In the SAMPERS system in Sweden, a more advanced procedure is followed. The model contains modules for Swedish citizens travelling to/from Sweden and foreign citizens travelling to/from Sweden that are handled separately from the modelling of national travel patterns.

Preferably, the future international transport should be estimated by models operating at the international level. However, only few EU-level transport models exist, examples are SCENES, NEAC and TRANS-TOOLS. The TRANS-TOOLS model system is owned by the European Commission. This is contrary to other European models that are owned by consultants. There is a wider spectrum of economic models covering international trade, e.g., CGEurope being one of the most prominent. In Scandinavian countries, for instance, country-specific economic models, which include international trade flows, have been developed.

12.2.3 National models
The purpose of national models is comparable to the purpose of the use of EU-level models. The difference concerns the coverage of the geographical area and the level of detail of the data and information. A national model focuses on one specific country, the data for this country are much more detailed while the data for the other European countries are much less detailed compared with the EU level models.

National transport models have been developed in many countries as tools for analyses of national transport policies (e.g., investment, operation, taxation and pricing policies). For instance, a description of the regional freight transport alone may not provide a reasonable and adequate description of the overall freight flows. Therefore, most freight models are indeed either national or international. Lundqvist and Mattsson (2001) and Daly (2000) provide a review of national modelling in European countries.

Nested trip or tour based logit models are state-of-practice in national modelling integrating the treatment of various choices concerning frequency, destination, mode, time of day, etc., and linking these to route assignment models. Such nested models constitute the core of the national demand models in the Netherlands, Norway, Sweden, and Italy. A quite different approach has been followed in the UK and in a number of cases more aggregate modelling techniques have been applied, e.g., in Hungary.

Most national passenger demand models are representing the behaviour of individuals and households based on disaggregate data with aggregation in the assignment step in order to reflect link flows and congestion. The British NRTF model starts from projections of aggregate traffic growth that are imposed on a statistical representation of road capacity in order to estimate speed changes and behavioural adjustments. Both the bottom-up approach in the Netherlands (NMS) and the British top-down approach have been applied during a long time period and they have both been susceptible to gradual improvements to serve new policy demands.

Some of the national models (e.g., the Dutch NMS and British NRTF) have been developed in a context of already existing regional models and have been inspired by and complemented
these. In other cases (notably the Swedish SAMPERS), a new modelling system has been developed to replace the less integrated regional and national models, which existed earlier.

Both the Dutch NMS and the Italian DSS use techniques that are not relying on major commercial software packages. This may contribute to flexibility in use and development but may on the other hand require more resources for model development and for acquiring skills of application. On the other hand, the open availability of, e.g., SAMPERS for potential users may be hampered by the licence requirement of the inherent software (EMME/2).

12.2.4 Regional models
Regional models as defined in Section 3.2 primarily consider passenger transport. At the regional level freight transport is done by road, since rail and inland waterways typically is used at longer distances only – i.e., between regions rather than within regions. In some cases, the freight transport is taken from the national model and combined with the passenger transport in order to make capacity restrained assignments. An example of such a model is the New Regional Model (NRM) in the Netherlands. Another example concerns the regional model for the cross border region Euregio Meuse-Rhin consisting of sub-regions in Belgium, Germany and the Netherlands. For this model, detailed data from the three countries had to be collected, estimated, and harmonised.

At regional level, the economic models mostly do not analyse the economic activities in themselves. They analyse how the regional or local economy is affected by changes in transport and infrastructure investments. This question is, e.g., discussed by Bannister and Berechman (2000).

12.2.5 Metropolitan models and urban models
Although there is considerable overlap between regional models and metropolitan models, metropolitan areas are characterised by high density, a well-developed public transport system, and high congestion on the road network. Commuter trains and underground trains are often part of the transit system in metropolitan areas. Slow modes are also important and may require more detailed modelling than in regional models.

Examples of metropolitan and urban models are Amsterdam, Hamburg, Stockholm, and Copenhagen models. Some of the metropolitan models are quite complex model structures based on the logit framework and advanced assignment models in an attempt to capture rather complicated mode interactions and congestion effects (see Section 13).

Freight modelling seldom plays a major role in metropolitan models, since the main relevance in urban modelling is distribution of goods by road. City logistics models involve either prescriptive/normative approaches (for single firms or groups operating as one) or descriptive approaches, where the latter do not take into account the logistics processes behind freight traffic. Mostly the techniques operated in descriptive models are direct demand models that do not take into account explicitly the choice of vehicle type.

Especially at the urban level, hardly any transport statistics are available to help with developing freight demand models. Where firm-level data are available, interesting
possibilities open up including detailed microsimulation. In the RESPONSE model in the Netherlands, a simulation approach is applied, where use is made of a mix of public and private data to develop a detailed spatial database of consumer goods movements, for purposes of microsimulation of logistics chains.

12.2.6 Corridor models

If the objective is to analyse transport behaviour in a particular corridor it may be appropriate to develop a model targeted to address the specific questions for that corridor and save cost to data collection, coding, etc. Such models only include passenger and freight traffic using the corridor or potentially future users.

Often corridor models focus on national or international travel, and many examples are available, e.g., EU corridor studies (TEN-STAC) and the Fehmarnbelt Traffic Model (FTC). The methodologies applied in corridor models range from rather simple mode choice and route choice models to complex procedures and sample enumeration (e.g., Euro Tunnel Model, Great Belt Model).

In international corridor models, it is necessary to consider a border barrier reflecting how various factors (border controls, differences in language, administration, culture, legal and social systems, etc.) contribute to traffic reduction. The impact of a certain policy on integration across the border is of high importance and difficult to forecast. One example of estimation and application of such a border barrier effect is included in the Oresundbelt Model (COMWIN) for travel between Denmark and Sweden.

12.3 Linking models of different scales

Developments on a worldwide scale can be very relevant on the EU, national, and regional level. For instance, the strong economic development in China results in a massive growth of containerised transport flows between China and Europe. This development also leads to increased container flows on a European, national and regional scale. Another example to illustrate the relation between the different scales is the impact of decisions about European transport policy. The European decision to promote the use of rail and inland waterways instead of road transport leads to changes in transport flows on national and regional level. While applying a specific model on a specific scale, it makes sense to analyse whether developments on another scale are relevant and might have an impact on the modelling results. For instance, while national models are concerned with effects (e.g., mode choice and travel frequency), urban models may concentrate on other aspects like congestion and time-of-day choices. It is crucial for estimating the influence of large-scale developments on local level that models of different levels are consistent with each other. For example, the import of Chinese products with maritime container transport to Rotterdam, which is redistributed from a terminal in Rotterdam to Ruhr area in Germany, can be considered from a European modelling level and regional modelling levels in Germany and the Netherlands.

For European modelling the movement from China to the Ruhr area via Rotterdam with maritime and road transport is important. For regional modelling in the Netherlands, the road transport from Rotterdam to the German border is important. For regional modelling in
Germany only, the road transport from the Dutch border to the final destination in the Ruhr area is important.

The linking of scale can be an integrated part of a new model system requiring a well-defined and organised structure. Linking existing model systems into a series of models to cover a larger study area or test complex schemes can only be preformed under certain conditions to be cost efficient. In practice, linking of existing models is a task of transfer of data and model results between the models in question. The issues are discussed in further detail below.

12.3.1 Integrated models system using different scales

In principle, issues at different levels may be addressed in a comprehensive model, e.g., mode and destination shifts by introduction of high-speed rail system and at the same time questions concerning local road traffic congestion. The computing time, however, may be unacceptable high even in case of only minor infrastructure changes making it more favourable to set up a system of models linked together. The SAMPERS system in Sweden, for instance, contains a special module for analysis of international passenger demand. It contains separate models for Swedish citizens travelling to/from Sweden and foreign citizens travelling to/from Sweden. The structure of the models for international trips is shown in Figure 12.1.

![Figure 12.1: Structure of the models for international travel to/from Sweden](image)

Two lines of approach may be followed: top-down or bottom-up. While the lower-level models in the top-down approach are conditioned on the higher-level models, the lower-level models in the bottom-up approach supply aggregated result to a higher level model. The national modelling in, e.g., Sweden, the UK, and the Netherlands are examples of the top-down approach, whereas Norway has a system of regional models as input to national transport modelling.
In SAMPERS, for instance, the models for international passenger transport, national passenger transport, and regional passenger transport can be used to investigate impacts at different scales. There is a direct link between long-distance travel analysed in the national model and the corresponding access/egress trips treated in the five regional models of Sweden. Thus, the model system can operate with different degrees of spatial detail using the national forecasts as input and constraint to the more spatial detailed regional models.

12.3.2 Linking of existing models and data
The TRANS-TOOLS model covering passenger and freight transport in Europe is an example of linking existing models into one common framework. It is developed and executed as a sequence of sub-models based on existing models:

- Passenger demand model (VACLAV, ASTRA)
- Freight trade model (NEAC)
- Freight mode choice model (NEAC)
- Freight logistics model (SLAM)
- Assignment models (CTT)

The experience from TRANS-TOOLS shows that many and often time-consuming tasks have to be solved and carried out before existing models can be linked together.

First, the existing models have to be re-estimated and recalibrated based on the inputs from related sub-models and networks. For instance, the assignment models have to supply LoS as input to re-estimation of the demand and logistic models. Furthermore, consistency in parameter values used in the different modelling steps should be achieved.

Second, the interface between the models has to be recognised and structured in detail. The interfacing includes descriptions of data inputs and outputs from the sub-models, design of databases, development of mutual database formats recognised by the sub-models, and routines for data conversions. Existing models may, for instance, use different zoning systems, segmentations (e.g., trip purposes, commodity groups), time-of-year and time-of-day splits. In the TRANS-TOOLS model, a NUTS 2 zoning system is used in the freight models, while the passenger model applies a NUTS 3 based zoning system. Thus, to aggregate passenger cars and trucks in the road assignment, a module was developed to convert trip matrices from NUTS 2 to NUTS 3. Another example from TRANS-TOOLS, is when yearly figures from the passenger and freight models need to be sliced into time-of-day periods to consider road congestion in the assignment.

Third, it is often necessary to conduct some new minor modelling tasks. In the TRANS-TOOLS model, for instance, much local traffic was not incorporated for assignment due to the large zones. However, to consider road congestion effects it is necessary to include local road traffic. Therefore, a simple routine was developed to estimate local traffic to be preloaded to the network before assignment.

Fourth, existing models often use different software packages. These may not be compatible. If a commercial software package is used in an existing model, license is required. Therefore,
either considerable extra costs are incurred to license fees or the model has to be transferred or programmed to another more open software package.

Recently, linking economic modelling with traditional transport modelling has become increasingly of interest to exploit the advantages of the two approaches. However, it is complicated due to the many inherent differences in the methodologies. Economic models, e.g., SCGE models operates usually on time-series data and aggregated scale, while traditional transport modelling is based on cross-sectional analyses and often applies a detailed spatial resolution to describe route choice accurately. Economic models estimate monetary flows by economic sectors based on, e.g., CPA classification, which is not easily compatible with the usually commodity classification in transport models, e.g., NST/R. Today, only few cases of linking of economic modelling and transport modelling are known, e.g., the national freight models in Norway (NEMO/PINGO) and TRANS-TOOLS. The revision of the national freight model in Sweden has included development of a SCGE model to calculate trade flows as input to mode choice and logistics modelling. In TRANS-TOOLS, attempts have been done to integrate a modified version of CGEurope with transport models mentioned above. However, it was decided to use a traditional trade model to calculate goods flows and use CGEurope for calculation of redistribution of economics and changes to GDP caused by changes in the transport system.

Since linking of different models and model scale often are complicated and expensive, in practice a more common approach is to transfer data and results between models. For instance, a European-level model may deliver international flows via external zones to national models. This allows a consistency between policies at EU level and national planning of transport, but it requires the formulation of baseline scenarios and a model that can produce reliable and sufficient detailed result as input to the lower-level models. In a study of a new fixed link across the Øresund, for instance, the international travel between Denmark and Sweden was estimated by SAMPERS and then it was imposed to regional models in Denmark and Sweden to calculate the effects more accurately.

EXPEDITE is an example of “bottom-up” approach were lower-level models are used to produce results at a higher scale. In the study, forecasts of passenger and freight transport at European level were produced based on national models by applying a meta-model approach. A large number of runs were made by the Dutch, Norwegian, Italian, Danish, and Swedish national models and results were transformed into population-specific tour rates and passenger-kilometre rates for alternative policies. These synthesised results were then used as a basis for forecasting. The weakness of this approach is of course that it only provides aggregated results at high-level scale, thus, no network flows will be available unless a framework for data input is developed at European level and complete coverage by national models is achieved.
13 Best practice experiences

The second deliverable (D2.2) of WP2 describes best practice experiences of applied transport models in Europe. Examples are categorised into six areas of modelling: 1) freight modelling, 2) passenger demand modelling, 3) economic modelling of transport, 4) assignment modelling, 5) mode specific modelling, and 6) linking of scales.

This chapter summarises the detailed descriptions in report D2.2.

Section 13.1 provides two examples on freight modelling: a EU-level example (TRANS-TOOLS) and a national level example (the Dutch SMILE).

Section 13.2 gives six examples on passenger demand models. The first illustrates the role of land use in transport models (MEPLAN and TRANUS). The second is an example of a demand model at national/regional level (SAMPERS). The third describes a trip-based regional model (Pilsen Region), while the fourth describes a tour-based regional model (OTM, Denmark). The fifth illustrates a prototype of activity-based modelling and is the only example outside Europe (Boston). The sixth and last example of demand is a multimodal transport and impact model (TRANSURS, Hungary).

Section 13.3 includes two examples showing the role of economic modelling in transport modelling. The first example is CGEurope in TRANS-TOOLS and the second is on linking of economy, energy, and environmental aspect (GEM-E3, EU).

Section 13.4 includes three examples on assignment. The first includes a timetable-based model for public transport with focus on regularity issues (DSB rail model, Denmark). The second on multi-class road assignment with intersection delays (Copenhagen, Denmark), and the third on assignment and toll assessment (toll road in Eindhoven).

Section 13.5 gives three examples on mode specific models: a rail model (UK national rail model), an airport model (MPL Katowice Airport model), and public transport model (PUTD, urban Polish transport model).

Section 13.6 has two examples on linking of different level in a modelling context. The first example is on linking using GIS at a European level (TRANS-TOOLS). The second example is on linking at a regional level (Euregio Meuse – Rhin, Germany).
13.1 Freight

13.1.1 A EU-level freight model, TRANS-TOOLS

Keywords: EU-level, freight, logistics

Objectives
The logistic part of TRANS-TOOLS (TNO, 2006a) is chosen as a best practice example on freight modelling. The working of the logistic module is based on SLAM, a module, that can be appended to the SCENES model. SLAM makes it possible to evaluate the impacts of changes in the logistic and transport systems within Europe on the spatial patterns of freight transport flows, through changes in the number and location of warehouses for the distribution of goods.

Exogenous input:
- Trade/transport matrix from Etis Baseline mode & trade module
- Network data
- Import data
- Split records
- Compute Location scores

Endogenous input:
- Matrix with split Records
- Location scores (r)
- Ranked regions (rr)

Exogenous input:
- Input for computation of costs
- Possibilities
- Parameters

Output matrices

Figure 13.1: Flow chart of the logistic module in TRANS-TOOLS
Methodology
The logistic module produces output that is to be used in the assignment model and in the economic model.

Output for the assignment model
For the assignment model, the logistic module will produce unimodal transport matrices based on origin, destination, mode, NST/R, tonnes, and vehicles.

Output for the economic model
The economic model needs generalised and monetary costs per origin, destination and commodity type. These costs can be computed from the assigning process (the logsum of the mode costs per segment). The origin and destination will be on NUTS 2-level and are the origin and destination of segments of a chain. The costs will be in €/ton.

Calibration of the Logistic Model
The calibration of the logistic module was carried out in two steps:
- Calibration of the region scores.
- Calibration of the transport volumes and the modal split.

Data issues
Two data sources were used for the calibration. The first is the number of employees per region in 2000 (Eurostat). This statistic is used as an indicator for logistic activities. This indicator is used because data about indicators like the throughput in distribution centres is not available. The number of employees per region is the best possible alternative, but not a very good indicator for logistic activities. This implies that the performance of the Logistic Module can be improved when better data becomes available.

The second source is the number of tonnes transported between two regions by each mode (ETIS-BASE). Using this data for the calibration has a small disadvantage, because ETIS-BASE is also used as input for the logistic module. Obviously, the modal split after running the logistic module will be quite similar to the modal split in ETIS-BASE. However, this is not really a problem, because the aim of the logistic module is to determine the usage of distribution centres and not to determine the modal split.

Applications
In the first step of the calibration, the region scores are calibrated. The region scores are used for ranking the regions according to attractiveness for logistic activities. The region scores are build up from three components: economic activity, centrality, and flexibility.

The region scores are computed for the five commodity groups (see Table 13.1) for which logistic activities are the most relevant. The ranking of the region scores for each of these commodity groups is compared to the ranking of the regions according to the number of employees per region. It turned out that the correlation coefficient for all five commodity groups is the highest in the case where the importance of economic activity is equal to 1 and the importance of both centrality and flexibility is equal to 0. This implies that the likelihood of a region being used as a distribution centre is fully determined by the economic activity.
This explains why the correlation coefficients are not very high. The parameter settings of (1, 0, 0) for importance of economic activity, centrality, flexibility for each commodity group are used in the next step of the calibration. These parameters can be found in the table ‘Nstr’ of the database ‘Logmod.mdb’.

<table>
<thead>
<tr>
<th>Nstr Code</th>
<th>Nstr Name</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Agriculture Products and Live Animals</td>
<td>0.554</td>
</tr>
<tr>
<td>1</td>
<td>Foodstuffs and Animal Fodder</td>
<td>0.759</td>
</tr>
<tr>
<td>5</td>
<td>Metal Products</td>
<td>0.589</td>
</tr>
<tr>
<td>8</td>
<td>Chemicals</td>
<td>0.647</td>
</tr>
<tr>
<td>9</td>
<td>Machinery, Manufactured Articles, Misc.</td>
<td>0.727</td>
</tr>
</tbody>
</table>

Table 13.1: Correlation coefficient between region rankings

In the second step, the logit parameters of the nested logit model were determined. It has been decided to fix the probability for each chain type in this stadium to the following settings: direct transport (0.5), transport through a European distribution centre (0.2), transport through a national distribution centre (0.25), and transport through a European and national distribution centre (0.05).

This implies that the logit parameter for the choice of chain type is not used. The fixed probabilities can be found in the table ‘Chaintype’ of the database ‘Logmod.mdb’. These probabilities can also be changed by experienced users only and are therefore not available for every user of TRANS-TOOLS.

The logit parameters for the chain choice and mode choice were varied to find the parameter settings with the best fit: logit parameter chain choice (0.00005) and logit parameter mode choice (0.005). These parameters can be found in the table ‘Pars’ of the database ‘Logmod.mdb’ and can also only be changed by experienced users.

A comparison between the number of tonnes transported through distribution centre regions (computed with these parameter settings) and the number of employees per region resulted in a correlation coefficient of 0.373. A comparison of the number of tonnes transported between each region by each mode (computed with these parameter settings) and similar figures obtained from ETIS-BASE shows a very good fit (correlation coefficient of 0.997). As explained before, this was to be expected. Finally, the modal split computed with these parameter settings is respectively 74.6 %, 6.9 %, 3.3% and 15.3% for the modes road, rail, inland waterway, and sea.

It can be concluded that the outcomes of the logistic module show a moderate fit with the number of employees per region. This is partly explained by the fact that the number of employees per region is not a very good indicator for logistic activities. The modal split is quite realistic. This indicates that the logistic module produces reasonable results.
13.1.2 A national freight model, SMILE

Keywords: national, freight, logistics

Objectives
Essential for a model is the notion that developments in freight flow demand are the result of changes in economic structures that create a demand and a supply of goods in specific geographic regions and form the basis for transport flows between regions.39

The general aim for the SMILE model is to get a better view on future developments in freight flows that use Dutch infrastructure. Therefore, we take two kinds of freight flows into account with separate treatment.

1. Freight flows that relate to the Dutch production and consumption structure (i.e., relationships to and from Dutch production units)
2. Freight flows that use Dutch infrastructure but do not have a direct relationship with the Dutch economy (this includes transit flows using Dutch ports for transhipment and intermodal change only).

Methodology
In general, a distinction can be made between product logistics and transport logistics. Product logistics has to do with the control of good flows from basic products, via inventories and intermediate production activities till the physical distribution of final products to the customers. The whole logistic process consists of several repetitious activities involving the basic activities production, inventory, and transport (PIT). Transport logistics involves the optimisation of the organisation of freight flows so that the utilisation of transport equipment is optimised, considering costs and quality elements such as reliability and speed.

With SMILE, some first steps have been taken to resolve the shortcomings in knowledge about the relationship between production, inventory, and transportation by a three level chain modelling approach. The first level concerns the linkage between manufacturing activities within product chains, the second concerns the modelling of stockholding within distribution chains, and the third relates to the movement and transhipments of goods within (multimodal) transport chains. Below we explain how these three levels have been operationalised in the model.

Production, Sales and Sourcing
At the first level, Make/Use Tables create the opportunity to set up a production function for each sector (if the sector produces only one commodity group for each commodity). In contrast to the prevailing models of sectoral exchanges of goods, in the SMILE model the conventional Input/Output modelling approach has been abandoned. The available Make/Use tables provide a detailed insight into the production factors connected to the activity of each sector, including the commodities that are produced and consumed. By linking production and consumption, product chains can be built that, when combined further, result in production networks.

39 This section is based upon Tavasszy et al. (1998b).
One of the main features of the SMILE model is the application of these production functions in the assessment of the effects of a change in final demand for one product group on all the others, through the production network. This new approach allows tracing, e.g., the effects of a 20% replacement of steel by composites in the car manufacturing industry on the volumes of freight flows. Moreover, the Make/Use Tables are very helpful in establishing the location pattern of both production and consumption.

After having determined the volume and nature of production and consumption at different locations, the spatial distribution of flows between these locations is calculated. This spatial distribution results from the sales and sourcing processes at each location. As trade theory tells us, it is a result of comparative price differences and the resistance of geographical, organisational, and institutional differences that have to be bridged. This part of the model provides the user with the trade relations in the Netherlands.

**Inventory**

The main function of the second level is to link trade relations to transport relations by considering warehousing services. A logistic choice model describes distribution chains. In the choice model, total logistic costs are calculated that account for handling, inventory, and transport costs for homogeneous product categories denoted as logistical families. A survey on product characteristics has been undertaken to support the model with real-life data.

Following the survey, new groups of products and market conditions were identified in which it is reasonable to assume that within these groups logistic choice behaviour is homogeneous. At present logistic families are distinguished using the following product and market characteristics: value density (the value of products per m³), packaging density (the number of colli per volume unit), perishability (the period in which a product is technically or economically usable), delivery time (in days), shipment size (in tonnes), and demand frequency.

In aggregate freight transport system modelling, this issue has not received the attention it deserves, particularly if one looks at the ongoing trend of “reconfiguring European logistics systems”. The existing aggregate modelling approaches, which combine production and network modelling, do not represent this second level. Neglecting this level may adversely affect the accuracy of modelled freight flows as well as the policy sensitivity of the model.

**Transportation**

At the third level, a multi-modal network (see Figure 13.2) for six modes of transport is available in SMILE. It is a strategic network, which means that only the network structure is modelled. Not all alternative links between regions are visible to the user, but only one representing all alternatives.

The underlying network used for calculations is modelled in analogy with the physical network. The figure above illustrates this network type for three modes. The optimal route in SMILE will be sought for every commodity type, and for every element in the logistics chain. The route choice disutility has a mode specific (see Baumol and Vinod, 1970), weighted cost
formulation where a combination is made of the physical distribution costs and time spent during transportation.

Figure 13.2: Multimodal network

The weights, which are used, are specific per goods type and reflect the opportunity costs of the resource “time” within the entire logistics process. Comparing this model with existing approaches in physical distribution (see, e.g., Goss, 1991; McGinnis, 1989; Jourquin, 1995; Vieira, 1992), the formulation is new within this complex setting (using empirical values for 50 logistical families, reflecting total logistic costs including estimated random preferences).

Data issues
Do we wish to give a forecast for one point in time or do we need information on the growth patterns of system variables? Insight in growth patterns gives insight in the existence of saturation levels and equilibrium mechanisms. Although two scenarios may produce similar results for a specific forecast year, they may show a completely different development in the years before and after the forecast year. The understanding of these dynamics is at least as important as the exact prediction of the levels in the horizon year under study.

Applications
The above stages of production, distribution and transportation form three steps in the calculation process. These are repeated in a cyclical simulation process, as illustrated in the figure above. Each simulation cycle represents a time span of one year; a complete simulation results in time series data related to transport flows and costs. Naturally, the intermediate output concerning economic activities, the exchange of goods, and the logistics service markets are obtained in a similar way and stored in the SMILE database.

The latest update for SMILE to the SMILE+ is that a growth factor approach is applied to a base year matrix. A pivot-point method is applied whereby growth factors are retrieved from the SMILE+ and applied to a detailed base year matrix.
13.2 Passenger demand best practice

13.2.1 Land-use/transport modelling: MEPLAN and TRANUS

Keywords: strategic, land-use/transport, quasi-dynamic, regional markets

The land-use/transport systems MEPLAN and TRANUS have a common origin in research and development within the Martin Centre for Architectural and Urban Studies and in the Centre for Land Use and Built Form Studies, University of Cambridge. During the 1980s, the development of the MEPLAN and TRANUS software systems was conducted within the two firms Marcial Echenique and Partners and Modelistica, respectively. The model systems are based on spatial input-output theory and spatial markets interacting through flows of passengers and freight in the transport systems.

Objectives
The aim of land-use/transport interaction (LUTI) models is to analyse the mutual relationships between location processes and transportation processes. This is done by modelling of spatial markets (land market, real estate market, markets for goods and services) and how these interact with transport markets. The models normally assume that the transport market represents a fast process that equilibrates with land-use without delay, while the slower spatial markets respond to the transport conditions of the previous period. LUTI models are developed mainly for multi-purpose strategic use.

Methodology
MEPLAN is a software package developed by MEP (now part of WSP Group). The software offers facilities to analyse the interactions between economic activities and transport at various levels from the strategic to the local. It is based on the following principles (LT Consultants, 2004):

- Transport is a derived demand from interactions between activities.
- Transport exerts an influence on the location of activities over time.
- Transport and land-use are treated as markets where the interaction between supply (networks and land) and demand (flows and activities) establishes the price of transport and land.

The model system can be classified as a spatial input-output approach with an endogenously determined pattern of trades affected by the transport flow equilibrium of the previous time period. The system includes a module for economic evaluation of overall costs and benefits and their distribution.

TRANUS is a software package developed by Modelistica (based in Venezuela), which combines a model for activity location and interaction, land-use and the real estate market, with a comprehensive multimodal transport model. It can be applied for any scale, from detailed urban to regional and national levels, and from very short-term pure transport projections to long-term strategic studies. Some features of TRANUS (LT Consultants, 2004):
Double purpose: simulation of probable effects of land-use and transport policies and projects and evaluation of these from social, economic, financial and energy points of view.

Roots in spatial interaction and discrete choice theories.

Graphic interface.

The quasi-dynamic structure of TRANUS is the same as the one outlined for MEPLAN: a transport equilibrium is established in every time period and affects the land-use/location developments of the next time period.

Data issues
Both frameworks are very general and synthetic and can be applied in contexts with very different data availability. The minimum requirement is a description of the transport networks, land supply and exogenous demand relating to “basic” industries. All additional information is used only for calibration.

The calibration of the models is a major undertaking. The interactive nature of the models implies that calibration of one part to fit observed values is dependent on the calibration of other parts. If the target data for calibration relate to several time periods, the dynamic version of the whole model must be run repeatedly. Some assistance can be provided by the software but calibration is mainly a complicated manual trial-and-error process requiring considerable experience.

Applications
Both MEPLAN and TRANUS have been applied in widely different contexts in planning and research. For examples of early applications, see Hunt and Simmonds (1993) and de la Barra (1989). Recent applications are reported in the PROPOLIS project, including four MEPLAN and two TRANUS urban implementations in the European context, LT Consultants (2004).

The diversity of applications can be seen as a major strength of the model systems. At the same time, it restricts the transfer of experiences between various applications. Parameter values can vary considerably between very similar applications. According to Hunt and Simmonds (1993), the accumulated experience is largely in terms of concepts, theories, methods, and modelling approaches, rather than in terms of key parameter values.

13.2.2 A national/regional forecasting system: SAMPERS

Keywords: tour-based, passenger transport, forecasting, international, national, regional

SAMPERS, initially developed 1998-1999, is a Swedish passenger transport forecasting system on the national and regional levels. International travel is also handled. The system of demand models is tour-based and interacts with equilibrium assignment models. Integration of modelling steps and a user-friendly interface was a key concern for the system. The main use is in strategic and tactical infrastructure planning on national and regional levels.
Objectives
The new SAMPERS system was designed to replace earlier models, which had been developed separately, to cover all trips, to add new features in demand modelling, assignment and impact assessment, and to provide an integrated and user-friendly system of state-of-the-art models. The model development and estimation should draw on recent data from national travel surveys.

Methodology
Nested logit models of passenger transport demand are formulated for:

- International travel to and from Sweden (670 domestic zones, 180 international zones)
- National travel, i.e., trips longer than 100 km (between 670 zones)
- Regional (and local) travel (five regional models with 1000-2500 zones each)

The structure of the various models in terms of the hierarchy of their constituent parts (frequency, tour choice, destination choice, mode choice, time-of-day choice, ticket type choice) is determined in the estimation process. The number of choice levels differs between the three model types. Simultaneous full information maximum likelihood estimation is applied, if possible. The main structure of most passenger demand models is outlined in Sections 7.1.4, 7.4.4, and 12.3.1.

The following travel purposes are considered:

- International: business and leisure (from Sweden), all purposes (to Sweden)
- National: business and private
- Regional: work, business, school, social, recreation, and other purposes

The following travel modes are considered:

- International: car (by road or ferry), bus, train, air, and ferry
- National: car, bus inter-city train, high-speed train, and air
- Regional: car as driver, car as passenger, public transport (divided into bus or train), walk, and bicycle

A separate call for tender concerning the traffic assignment models of SAMPERS resulted in the decision to use the EMME/2 models (equilibrium car assignment, frequency-based public transport assignment, and long distance timetable-based assignment).

Modules for assessment of impacts (safety, emissions, energy, operating and maintenance costs), cost benefit analysis and accessibility evaluations make up other parts of the model system.

Data issues
The main data source for estimation of the passenger demand models of SAMPERS is the Swedish national travel survey 1994-1998. For international travel, other surveys in connection with the Öresund and Fehmarn Belt studies were also used. SIKA (Swedish
Institute for Transport and Communications Analysis) provided transport system data from the EMME/2 system. Socio-economic data were delivered by Statistics Sweden for the Small Area Market Statistics (SAMS) spatial subdivision.

**Applications**
The model system is designed for general use in strategic and tactical planning contexts on the national and regional levels:

- Demand effects of new infrastructure or new services (projects, programmes)
- Demand effects of, e.g., income, population and employment changes
- Impact assessments: safety, environment, energy, accessibility, regional development, etc.
- Assessment of pricing and regulation policies: taxation, tax deductions, road pricing, area licensing, road tolls, rules for company cars, etc.

SAMPERS is reasonably well documented in English (overview, estimation/calibration/validation of passenger demand models). Other manuals are only written in Swedish. The demand models and the user interface are available in open source code, while the assignment models are licensed products.

The requested flexibility and comprehensiveness of the system made it quite complex. It handles large quantities of data and hundreds of parameters and variables, which must be controlled by users of the system. The owner of the system can define one or several complete set-ups of scenario data (socio-economic, demographic, traffic system and policy variables). The user can copy the default scenario, make changes of the scenario and run a forecast and an evaluation. An information control system informs the user (and anybody else interested in the results) about the deviation from the defined base scenario.

The user-friendly model interface (scenario formation, running mode, presentation and comparison of results, impact assessments) helps to manage the complex system. Running times for scenarios involving many of the sub-models and feedbacks between demand models and assignment models are still restrictively long. This is mainly due to the spatial and socio-economic detail. One remedy is to develop sketch-planning versions with less socio-economic detail. Another option would be to use the possibility of implementing parallel computations.

### 13.2.3 A trip-based transport model from The Pilsen Region,

**Keywords:** tactical, trip-based demand model, regional, passenger transport

The Pilsen Region transport model is an example of classical four-step transport model based on trips. This model was developed by SUDOP PRAHA a.s. for the Transport Conception of the Pilsen Region.
Objectives
The main goal of the Transport Conception of the Pilsen Region project was to analyse the current status in transport demand and supply, and to propose the set of measures and priorities that can have positive influence on transportation in the Pilsen Region in future. The transport model of this region was developed for testing the possible transport measures. This model covers important modes of passenger transport. Following the European transport policy priorities, especially the possible modal shifts between private and public transport have been tested. The results of this project can have strong influence on the land-use plan of the region and also to the general future development of the Pilsen Region.

Methodology
The Pilsen Region model covers the NUTS 3 Pilsen Region area and the surrounding area in Czech republic and Bavaria. The model consists of 158 internal zones, 24 external zones in Czech republic and 12 external zones in Bavaria. The traffic was calculated with detailed disaggregated supply-demand model in four steps:

1) Trip generation was based on defined “activity chains” for each defined socio-economic group. Activity chains describe probability of making some set of trips during an average day (e.g., Home – Work – Shopping – Home). Socio-economic groups consist of groups with similar transport behaviour (e.g., employed persons with car).

2) Trip distribution was based on a gravity model. Input data for the gravity model were attractiveness of zones and deterrence parameters disaggregated per activity and socio-economic group.

3) Mode choice has been done by a MNL model (for car driver, car passenger, public transport, and walk) using indicators like access/egress time, travel time, costs and other travel conditions (frequency and interchanges for PT) in the utility functions.

4) Assignment was equilibrium assignment for the car traffic and frequency-based assignment for the public transport.

Models have been calibrated to reflect conditions on an average weekday in the 2005 base year. The frequency, mode, and destination models operate at the all-day level. Prognosis of demand has been made for years 2020 and 2030+. For analysis of the capacity problems on the road network, afternoon peak-hour matrices were made. Except of these cases, all calculations were made with all-day matrices for public and private transport.

Data issues
The main data describing the transport infrastructure and zone borders are based on data from The Pilsen Region GIS and Land-use plan. The socio-economic data were obtained from the Czech Statistical Office. The problem that transport behaviour data is not statistically described at regional or national level were solved by a survey made directly for use in the demand part of the developed transport model.
Applications
The developed transport model helped to answer the (main) questions:

- What impact will proposed measures have on future modal split.
- Where will future bottlenecks occur in the road network.
- Where will it be useful to reorganise lines and timetables of public transport.
- Which railway lines with very low traffic should be replaced by buses.
- Which roads with very low traffic should be changed to cycle tracks.
- Is it useful to create a regional ring around the city of Pilsen.
- Which main roads should be changed to secondary roads and vice versa.

13.2.4 A tour-based model in Copenhagen, OTM

Keywords: tactical, tour-based demand model, regional

The Ørestad Traffic Model (OTM) is an example of a demand model based on tours instead of trips. In this respect, it is a hybrid demand model in-between the classical four-step model and newer activity-based approaches. It is a tactical model for the region of the greater Copenhagen.

Objectives
The base of this model is a classical four-step demand model. The model was updated to its fifth version in 2007. A specific feature of the model is that home-based trip generation is based on tours. The model was initially developed for the planning of the new city area, The Ørestad, but now it is in use for general assessment of transport projects in the Copenhagen area.

Methodology
The OTM predicts demand for transport across The Greater Copenhagen Area (GCA) in Denmark. The GCA covers the city of Copenhagen and the surrounding area of the islands of Amager and Zealand in the eastern part of Denmark. In the model, GCA is divided into 835 zones, where 818 are intern zones. The OTM model system predicts demand for travel by seven separated passenger purposes.

The OTM 5 models consist of separate model components by purpose for:

- travel frequency (generation) at the all-day level.
- for passenger purposes, mode, and destination choice with five modes distinguished:
  - car driver,
  - car passenger,
  - public transport,
  - bike,
The models have been calibrated to reflect conditions on an average weekday in the 2004. The frequency, mode, and destination models operate at the all-day level. Prior to assignment, the model predictions are split between the seven model time periods distinguished in the assignment models using fixed factors. The seven model time periods are: 21:00-05:00, 05:00-07:00, 07:00-08:00, 08:00-09:00, 09:00-15:00, 15:00-18:00 and 18:00-21:00.

For passenger trips, assignments are undertaken for each combination of six travel purposes, seven model time periods and five modelled modes. For freight trips, assignments are undertaken for each combination of two travel purposes and the seven model time periods. Once the assignments have been run for each model time period, all-day level-of-service is generated to feed back into the demand models.

A special feature of the model is the fact that it is tour-based. The home-based tour models predict the number of full tours made by an individual on an average weekday (i.e., Monday-Friday where summer months (June, July, and August) are omitted). A full home-based tour is a series of linked trips starting and finishing at the traveller’s home. The purpose of the tour is determined by the activity undertaken at the Primary Destination of the tour.

Data issues
The main data input comes from the national household-based travel survey in Denmark, TU. Whereas derived indicators such as VoTs and WTPs are derived from the newest Danish WTP study, DATIV.

Applications
The main output is demand at link level segmented by mode, purpose, and time of day. Forecasting can then give derived output such as demand elasticities or impact assessment of new transport infrastructure.

13.2.5 The Boston activity-based model – a prototype
Keywords: activity-based, demand model, tour-based

The purpose of the prototype was to demonstrate the concept of the activity schedule model system, test important features, and gain an initial evaluation of the method’s potential for further research and operational implementation.

Introduction
The description contained here is based on Bowman and Ben-Akiva (2001), where a prototype version of Bowman’s original model from 1995 is described. The model is a prototype of the day activity schedule model system, developed using data from the Boston metropolitan area, including a 24 h household travel diary survey collected in 1991, as well as zonal and time-of-day-specific transportation system attributes from the same time period. Survey respondents reported activities requiring travel, and details of the associated travel.
Prototype specification
The probability of a particular activity schedule can be expressed in an activity-based model as the product of the marginal pattern probability and a conditional tours probability:

\[ p(\text{schedule}) = p(\text{pattern})p(\text{tours/pattern}) \]  \hspace{1cm} (1)

To implement the basic structure of (1), the prototype groups the elemental decisions of the activity schedule into five major tiers, including

1. activity pattern, which is the marginal model of Eq. (1), plus four tiers that together constitute the conditional tours model system:
   a. primary tour time of day,
   b. primary destination and mode,
   c. secondary tour time of day,
   d. secondary tour destination and mode.

The activity pattern is a nested logit model. It represents the choice between a pattern with travel and one without. The upper level is a binary choice between staying at home all day and a pattern with travel. Given the choice of a pattern with travel it also includes the conditional choice among 54 patterns with travel.

Evaluation of the prototype
The purpose of the prototype was to demonstrate the concept of the activity schedule model system, test important features, and gain an initial evaluation of the method’s potential for further research and operational implementation. A number of simplifications were introduced that may limit the prototype’s prediction capabilities. Here some of these limitations are summarised, giving special attention to impact on model performance and the prospects for remedies in subsequent development.

Time-of-day models
The weakest components of the model system are the time of day models because level-of-service variables are not included. However, these models interact with other policy sensitive dimensions of the activity schedule via the conditionality hierarchy. As a result, while timing choices are not influenced by transportation system level of service via travel accessibility, they are affected indirectly by accessibility’s influence on the activity pattern, and the conditioning of time of day on the pattern choice. The time-of-day dimension is defined very coarsely so that, even if the model specification was enhanced to include accessibility’s direct influence, the responsiveness to level of service would be crude. Effectively incorporating time-of-day choice requires finer resolution of the time-of-day dimension, accessibility linkages with the other dimensions of the model system, and better explanation of time of day choice. The lack of a strong time-of-day component does not, however, undermine the ability to capture inter-tour trade-offs in the activity schedule, an important improvement over tour-based models.

Secondary stops on tours
This dimension is missing entirely from the prototype, and reduces the ability of the model to accurately represent inter-tour trade-offs involving trip chaining, one of the important features
of the model design. Without secondary stops, the model relies too heavily on matrix adjustments for stops during not modelled model system operation. For example, it cannot capture correlation among destinations of stops on a tour. This simplification is not inherent to the proposed design, and the secondary stops can be included in an enhanced implementation, as they are included in existing tour-based model systems.

**Activity pattern model**
This model explains very little of the observed variability in pattern choice, with measurable but small responsiveness to transportation policy via the accessibility variable. The proposed system structure provides an excellent context for further research and development into the factors influencing pattern choice, such as demographic outcomes and lifestyle decisions. Prospects of improving the measurement of activity and travel accessibility’s influence are also good, through the enhancement of the tours portion of the model structure.

**Nesting hierarchy**
Although the hierarchical relation of activity pattern to tours is statistically established in the prototype, and provides a clear advantage over existing operational econometric models, several important structural issues were not fully analysed, including

(a) the relation of the time of day decision to the mode and destination choice,
(b) correlations within tiers,
(c) cross-correlations not accommodated by nested logit.

Further research and development may lead to important structural model enhancements.

**Values of time**
Unrealistic values of time indicate model specification errors and/or data deficiency that were not resolved in the prototype. As specified the model would produce counterintuitive predictions in some cases. Achieving realistic values is a reasonable pre-requisite for final acceptance of the model, calling for more specification testing with new data.

**At-home activities**
The prototype does nothing with at-home activities because such information was not collected in the Boston survey. This limits the ability of the prototype to fully capture the activity basis of travel demand, but does not prevent the capture of basic at-home versus on-tour trade-offs and inter-tour trade-offs. Data availability is an important concern, and further research and development may sharpen understanding of data requirements enabling more efficient collection of the most important at-home information.

13.2.6 TRANSURS, Multimodal Transport and Impact Model

Keywords: tactical, tour-based demand model, regional, congestion pricing

TRANSURS – acronym stands for Transport in Urban and Regional Systems – is an in-house transport model developed by TRANSMAN Consulting covering demand modelling and impact calculation. Instead of the classical four-step theory, the model is based on daily
trip chain modelling, so the home-based and non-home based trips are dependent on the initial mode choice. The model was developed for Budapest and its surrounding based on the household surveys from 1992-94.

Objectives
Transport systems should be understood as a space-time-cost system. The interaction among available modes, the capability of the different user groups and the variable attributes of supply are the basic characteristics of the passenger transport system. In many cases, the policy and measure assessment requires such models that are able estimate the possible effects in demand modelling as whole. A direct driver of the model development was the investigation of the impacts that could be caused by theoretical road charging measures regarding the energy savings in Budapest in EUROPICE (Energy efficiency of Urban ROad PRicing Investigation in Capitals of Europe) RTD 4th FP project.

Methodology
The TRANSURS model package contains the determination and distribution of the passenger and freight flows, the calculation of the road and public transport network loads and the quantification and evaluation of the different impacts (time, operation cost, air pollution, noise etc.). The passenger traffic was calculated with detailed supply-demand models, while at the freight transport simpler grow-factor models have been used.

The passenger demand models describe trip chains by activity, car availability, and public transport pass ownership. The main features of the passenger model are:

- **Trip generation:** the mobility (trip rates) of a given group is influenced by the “potentials” of the origin zones.
- **Trip distribution:** the destination choice is modelled in two steps: first a logit choice model was used for determining the greater area relations from the given origin zone and secondly the flows were distributed inside each area with a simpler gravity weight model.
- **Mode choice:** it is done by a MNL model (for car driver, car passenger, public transport, bike, walk) using travel time, costs and other travel conditions (frequency and interchanges for PT, parking space availability and fees for cars) in the utility functions.
- **Assignment:** equilibrium assignment is used for car and truck (bus) traffic; frequency- and schedule-based assignment for public transport.
- **Value of Time:** is derived from the revealed logit analysis of mode choice.
- **Traffic volume dependent indicators**
  - time-fuel consumption, operation costs and air pollution
    The calculation method is based on the link traffic loads resulted from the assignment. It calculates the consumption for links and nodes. The determination of the used fuel considers the traffic conditions and is done for cars, trucks and buses.
Relation based indicators
For the scenario evaluations by MCA the model uses an approaching method to assess the socio-economic potential. The approach is based on the accessibility calculations and structural attributes of zones (e.g., net tax revenue, age distribution, skill level of workers)

The model calculations are carried out in one single step – unlike the former separation of trip generation, distribution, and splitting. The daily and peak-hour modal traffic flows of the entire city can be gained by working through all zones, traveller groups and chain types.

Another important feature of these models is that connections and results are more dependent on the supply characteristics of the transport system (time, cost, service characteristics).

Data issues
The transport models were based on household surveys from 1992-94. The year of calibration was 1995. Besides the road network, the network model also contained the public transport network.

Applications
The primary use of TRANURS was the calculation of the road charging (access fee) effects. Later a number of projects utilised its capabilities and results for, e.g., passenger behaviour analyses, public transport network optimisation, investigations of the M0 ring-motorway around Budapest, and the investigations in connection with the establishment of the Budapest Transport Association.
13.3 Economic model best practice

13.3.1 CGEurope, TRANS-TOOLS

Keywords: Computable general equilibrium, European model, regional distribution, part of model complex

CGEurope is a European CGE model that is modified for the specific use in TRANS-TOOLS. The basic structure of the model remained the same in the two model versions. The version reported here is the version applied in TRANS-TOOLS. An important difference between the two model approaches is that there is only one sector in the TRANS-TOOLS version due to a concern within the Consortium that the detailed model would prevent users from having full flexibility of using the model (e.g., in determining the tested scenarios).

Main characteristics
CGEurope is a spatial general equilibrium model for a closed system of regions covering the whole world. All of regions are treated separately and are linked through endogenous trade. The zoning system with 270 regions includes 268 study-area NUTS2 regions, and 2 rest of the world regions. The model is comparative-static, which means that for each scenario analysis two equilibriums are compared.

In each region there is assumed to dwell a set of households, owning a bundle of immobile production factors that are used by regional firms for production of goods. We distinguish between two types of goods, local and tradable. Local goods can only be sold within the region of production, while tradables are sold everywhere in the world, including the own region.

Producers of local goods use factor services, local goods, and tradables as inputs. The output of locals is assumed to be completely homogeneous, and is produced under constant returns to scale. Firms take prices for inputs as well as their output as given, and they do not make any profits. Instead of directly selling this output to households or other producers, firms can use it as the only input needed to produce tradables. The respective technology is increasing returns to scale. Tradable goods are modelled as being close but imperfect substitutes, following the "Dixit-Stiglitz" approach. Different goods stem from producers in different regions. Therefore, relative prices of tradables do play a role. Changes of exogenous variables make these relative prices change and induce substitution effects. For producers of tradables, only input prices are given, while the output price can be set under the framework of monopolistic mark-up pricing. Due to free market entry, however, profits are driven to zero, as they are in the market for locals.

Households are assumed to act as utility maximisers, taking all prices as given. Utility emerges from consumption of local goods and a composite of tradables, consisting of all, regionally produced and imported variants. Utility is modelled such that households appreciate a higher number of variants of tradables. The same income spent on more diverse variants means higher utility for the households. In other words, they share the "love for variety". For the sake of simplicity, all components of final demand, that is private and public consumption and investment, are subsumed under household demand. There is no explicit
consideration of a separate public sector. As a consequence of perfect price flexibility, the regional factor supply is always fully employed. Apart from factor income, disposable income contains a positive or negative net transfer payment from the rest of the world, depending on whether the regional current account with respect to all other regions has a surplus or a deficit. These transfers are held constant in our simulations. They are negligible with regard to quantitative results, but needed for keeping budget constraints closed.

Two features that give the CGEurope model its spatial dimension are:

- The distinction of goods, factors, firms and households by location, and
- The explicit incorporation of transport cost for goods, depending on geography as well as national segmentation of markets.

The term "transport cost" for interregional trade is used as a shortcut for any kind of trade-related costs. Usually trade costs are assumed to depend on the quantity of goods traded. Some costs of interregional transfer, especially costs of information exchange and insurance costs, depend on the value rather than the quantity traded, however. Letting trading costs depend on the value of trade makes the model much simpler, and we therefore prefer this assumption.

**Transport costs**

Two kinds of trade costs are used: costs related to geographic distance, and costs for overcoming impediments to international trade. The first are modelled under the assumption that transport costs are increasing with distance but at diminishing rate. The values for the second type of costs are calibrated within the model and include tariffs, but also, and more important, all costs stemming from non-tariff barriers, like costs due to language differences, costs for bureaucratic impediments, time costs spent at border controls and so forth. Transport costs are modelled according to the modified iceberg assumption, which implies that the value of transported goods in the origin and in the destination are the same. This is equivalent to modelling a zero-profit transport sector.

The new feature of the model is the possibility to take account of the revenues from pricing. This is a very important improvement, given that road pricing and measures alike constitute a large share of cost changes in the scenarios to be tested. Unlike the cost information, which is provided on OD basis, the revenue information is only available as total amounts generated by region. If the iceberg assumption is preserved, these revenues cannot be simply added to household budget in the given region, because the transport service is supposed to be zero-profit. The way to handle this problem is to assume that additional revenue is not merely a monetary amount, but is a true resource that is increasing productivity in the country, in which revenue is generated. Thus, in CGEurope this additional resource generated in each country is summed up and then redistributed (proportional to regional GDP) to the regions by increasing regional productivity parameter in the production function. As a result, the income effect of the pricing scenario is taken into account in a consistent way.

**Output**

The output of CGEurope to be used in the TRANS-TOOLS model is the change in regional GDP with respect to a reference scenario. For other purposes, CGEurope provides
13.3.2 Interacting economy, energy system, and environment, GEM-E3

Keywords: Linking, economic modelling, energy and environment

Objectives
GEM-E3 aims at covering the interactions between the economy, the energy system, and the environment. It is an applied general equilibrium model in which the world is divided into 18 zones that are linked together with endogenous trade. Each of the zones has the same model structure, but parameters and variables are zone specific. The economy is divided into 18 sectors. Four of the sectors are involved in the supply and distribution of energy and the remaining sectors are broad aggregates of the rest of the economy.

The production in each sector is modelled by using a nested constant-elasticity-of-substitution (CES) production function. The use of inputs and primary factors in each sector follows from a procedure involving several steps; at each step, inputs and primary factors are optimally combined according to a constant-returns-to-scale CES production function and the producer behaviour is modelled on the basis of standard assumptions about profit maximisation in a perfectly competitive environment.

Methodology
The two primary factors of production are capital and labour. The labour market is assumed perfectly competitive and total labour supply is determined by households that maximise their utility functions. For each period, the model endogenously allocates the available labour force over sectors. Capital is a quasi-fixed variable, and is defined in a way that allows firms to change next year’s capital stock by investing in the current year. It is further assumed that the stock of capital is immobile between sectors and countries.

Government activities are modelled almost in the same manner as the other sectors of the economy. Thus, the use of inputs is determined through cost minimisation. However, the remaining parts of government activities (expenditures, investment demand and tax levels) are exogenous. Financing of government expenditures is provided from nine different sources of government revenues: indirect taxes, environmental taxes, direct taxes, value-added taxes, product and export subsidies, social security contributions, import duties, foreign transfers and profits or losses from state-owned firms.

The households are modelled as one representative household, which can supply labour, save, invest and consume thirteen consumer goods. The representative household allocates its resources in an inter-temporal environment. The household’s consumption behaviour is derived from utility maximisation, and consists of two steps. Firstly, the household allocates its resources between future and present consumption, given the wage rate, the interest rate and the long-term time preference. Secondly, the household takes total consumption in a period as given and makes an intra-temporal decision about how to divide the total consumption between the different consumer goods in the economy.
The demand for products by the household, the producers, and the public sector constitutes the total demand. It is allocated between domestic products and imports, following the Armington specification. In this specification, cost minimising sectors and households use a composite commodity that combines domestically produced and imported goods, which are considered as imperfect substitutes.

The GEM-E3 model also distinguishes between goods imported from EU countries and those from the rest of the world. An index for optimal allocation of imported goods according to country of origin and price is calculated, and this index price is then used to allocate consumption between the imported and the domestically produced goods, as discussed above. It is further assumed that countries apply a uniform rule for setting export prices, independently of the country of destination. The Armington assumption implies that the various countries within the European Union can supply exports at different prices.

Data issues
The model has been estimated for the EU economy in 1995 and 2020. In all the scenarios of the study: baseline or business-as-usual (BAU), concentrated, diversified and uniform. The data come from EUROSTAT (1995 input-output table of the EU economy), and from the GEM-E3 model, which computes endogenously the model parameters for all scenarios in the year 2020.

Applications
The main types of issues that the model has been designed to study are:

- The analysis of market instruments for energy-related environmental policy, such as taxes, subsidies, regulations, pollution permits, etc., at a degree of detail that is sufficient for national, sectoral and Europe-wide policy evaluation.
- The evaluation of European Commission programmes that aim at enabling new and sustainable economic growth, for example the technological and infrastructure programmes.
- The assessment of distributional consequences of programmes and policies, including social equity, employment and cohesion targets for less developed regions.
- The consideration of market interactions across Europe, given the perspective of a unified European internal market, while taking into account the specific conditions and policies prevailing at a national level.
- Public finance, stabilisation policies and their implications on trade, growth, and the behaviour of economic agents.
- The standard need of the European Commission to periodically produce detailed economic, energy, and environment policy scenarios.

Policies that attempt to address the above issues are analysed as counterfactual dynamic scenarios and are compared against baseline model runs. Policies are then evaluated through their consequences on sectoral growth, finance, income distribution implications, and global welfare, both at the single zone level and for the EU taken as a whole.
The model is designed to support the analysis of distributional effects that are considered in two senses: distribution among European countries and distribution among social and economic groups within each country.

The former issues involve changes in the allocation of capital, sectoral activity and trade and have implications on public finance and the current account of member states. The latter issues are important, given the weakness of social cohesion in European member-states, and regard the analysis of effects of policies on consumer groups and employment. The assessment of allocation efficiency of policy is often termed “burden sharing analysis”, which refers to the allocation of efforts (for example taxes), over member-states and economic agents. The analysis is important to adequately define and allocate compensating measures aiming at maximising economic cohesion. Regarding both types of distributional effects, the model can also analyse and compare coordinated versus non-coordinated policies in the European Union.

Technical progress and infrastructure can convey factor productivity improvement to overcome the limits towards sustainable development and social welfare. For example, European RTD strategy and the development of pan-European infrastructure are conceived to enable new long-term possibilities of economic growth. The model is designed to support analysis of structural features of economic growth related to technology and evaluate the derived economic implications for competitiveness, employment, and the environment.

Figure 13.3: Structure of the GEM-E3 model
13.4 Assignment best practice

13.4.1 A rail punctuality model, Copenhagen

Keywords: schedule-based, public transport assignment, reliability, regional

Objectives
The Copenhagen Suburban Rail Company (DSB S-tog) has so far only measured train reliability (cancelled trains) and punctuality (delayed trains). However, it has long been desired that also passenger delays should be measured. This is defined as the delays passenger experience when arriving at the destination compared to the arrival time according to the planned timetable. The purpose of quantifying rail delays is two-fold:

1) to be able to deliver more detailed reports on passenger delays to The Ministry of Transport and Energy;
2) to provide a better basis for planning in the rail company. This includes designing timetables and disposing the rolling stock with respect to passenger flows.

Methodology
The third generation model, see Section 9.3.4, used assumes that passengers are planning their optimal desired route according to the official timetable. However, if delays occur over a certain threshold during the trip, the passengers are then assumed to reconsider the route at that point in time and space along the route. If a train is completely cancelled, they reconsider their choice without a threshold.

The main benefit of the model is that it is more realistic and precise than the prior generations of passenger delay models. The disbenefit is that it is more complicated to implement, and that the calculation time is larger, since the route choice model has to be re-run at the point in time and space where the schedule is delayed.

The model uses the optimal paths (or paths taking expected delays into account) in the planned timetable for two purposes 1) to compare planned travel times with the ones in the realised timetable, and 2) to estimate an a priori path choice strategy for the passengers. A 1st or 2nd generation passenger-delay model is therefore used to calculate the initial solution for the 3rd generation model.

A core assumption is that the paths are stored as a sequence of lines (each with a specific run) and transfer stations. The passengers are assumed to try to follow the same sequence of transfer stations and lines as planned, but they may use different train runs by each line. This is somewhat similar to a rule-based assignment. In order to make this feasible, the rule-based network and diachronically graph interacts by pointer structures that are built in memory as the graph is built (somewhat similar to the principles in Nielsen, 2004a). This is described further in Nielsen and Frederiksen (2007). To ease the formulation of the model, it distinguish between whether the planned routes contain transfers or not (Nielsen and Frederiksen, 2005).
Simplifications in the first phase of the work

The complexity of timetable-based public transport networks – and the size of the underlying calculation graph – quickly becomes extremely comprehensive. This is due to the time dimension, where all departures for each line must be handled. Therefore, some simplifications were decided:

- Only the suburban rail system was considered.
- The model is deterministic concerning the passengers’ choice functions (opposite to the prior references by Nielsen), this made it possible to analyse the impact of delays exclusively without mixing this with the other stochastic elements.\(^40\)
- The model runs on a station-to-station OD matrix. Only a daily average time-space OD matrix is presently available.\(^41\), whereby the choice functions cannot be multi-class as in, e.g., Nielsen (2000).

Practical use of the model

The OD matrix is based on a yearly traffic count of all passengers. It is segmented on one-hour intervals, within which demand is assumed uniformly distributed and segmented into smaller intervals. Desired departure times within these intervals are simulated randomly for each OD pair (launches). The urban rail store 3 variants of the timetables in their data warehouse:

1. The published (norm) timetable, i.e., the main principal timetable.
2. The planned timetable, i.e., the specific timetable that is planned for the specific day, this differs from the published timetable by including planned and announced changes, including delays and cancellations, e.g., for a planned track repair project.\(^42\)
3. The realised timetable that describes the actual operation during the day, including non-planed cancellations, delays, etc.

Typically, the realised timetable is compared to the planned, since the passengers are assumed to be aware of the announced changes. However, the planned timetable can also be compared to the published in order to evaluate the passenger inconvenience (time loss) due to planned changes. The costs of not announcing planned delays can in addition be evaluated by comparing 3) with 1) and base the planned route on 1) instead of 2).

Data issues

The model was implemented in order to run on the data warehouse for rail delay data used by the Copenhagen Suburban Rail Company (DSB S-tog). For a given day this automatically collect and store the planned as well as realised timetable including delays and cancellations. The assignment model is run during the night after the data warehouse has loaded and

\(^{40}\) A new version has now been implemented which include overlapping routes (Probit-based error term) and random coefficients as in Nielsen et al. (2001).

\(^{41}\) A new project is developing a time-segmented OD matrix estimation method based on counts from counting trains.

\(^{42}\) It is quite common that the planned timetable differ from the published somewhere in the network, especially in the evenings hours and weekends, where most planned maintenance occurs.
prepared the timetable data. The result is a daily measurement of passenger delays. All information is stored (each run with each line, as well as all transfers), whereby information can be aggregated to any level the user wants.

Applications
The application showed that it is indeed possible to implement and run the model for a network of the size of the Copenhagen Suburban Rail network. Dependent on the amount of delays, the run time of the model is 5-10 minutes, since routes are recalculated when delays occur, the calculation time increase with the irregularity of the schedule.

The resulting passenger delays differed largely from the train delays in the Copenhagen suburban rail network. The difference between the train punctuality and passenger delays is due to the different number of passengers in the trains during the day, transfer between lines, and the fact that the passengers (to some extent) will change routes due to delays.

13.4.2 An assignment model for car travellers in Copenhagen

Keywords: route choice, assignment, mixed logit, equilibrium, regional

Here we present a large-scale stochastic road-traffic assignment model for the Copenhagen Region. The model considers several classes of passenger cars (different trip purposes), vans, and trucks, each with its own utility function on which route choices are based. The utility functions include distributed coefficients estimated on stated preference data in a mixed logit model and later calibrated against GPS data. In application, the different classes and types of vehicles influence all the speed-flow relationships on links within an equilibrium framework. Sub-models for intersections and roundabouts describe queues and geometric delays.

Objectives
The purpose of this model has been to provide as precise assignment as possible in a number of models in the Copenhagen region. Three examples are assessment of a Harbour Tunnel in 1998 (see Paag et al., 2002), modelling of GPS data in the AKTA (Nielsen, 2004b) experiment in 2003, and environmental assessment of road pricing in the IMV project in 2006 (see Rich and Nielsen, 2007).

Methodology
The basic methodological framework for the assignment model follows the Stochastic User Equilibrium (SUE), see Chapter 9. However, it has been extended in various ways to include more complex utility functions Nielsen (1996), user classes Nielsen (1998a) and delay functions Nielsen et al. (1998).

Each user class chooses routes according to its own utility function. But the time-components in the utility depend on the choices of the other classes due to congestion at link level and intersection priorities. At link level, the traffic in each direction influences each other on two-lane roads by a modified BPR formula Nielsen et al. (1998). In addition the truck fractions calculated from the assigned traffic influence the capacity Nielsen et al. (1998). The links are divided into a number of types, each with its own speed-flow relationship. At intersection level, separate models describe different intersection types (ramps, unprioritised, prioritised, signalised,
roundabouts, and other types). Turn movements influence each other when relevant Nielsen et al. (1998). In signalised intersections, the effects of protected phases and signal co-ordination are included (by a platooned arrival model). In addition geometric delays are modelled; that is the difference between modelled speed according to the speed-flow curves at link level and the speed during acceleration and deceleration to and from intersections.

The model is solved by simulation using the Method of Successive Averages (MSA).

**Generalised utility function**

The utility function (which defines the route choice cost by summing for each road link) can be written as:

$$ U_i = (\beta_t + \xi_t) \cdot \text{time} + (\beta_c + \xi_c) \cdot \text{cost} + \varepsilon_a, $$

where:

- $\beta$ are coefficients that multiply time and cost;
- Travel time is dependent on the amount of traffic both on roads and in junctions, and is therefore influenced by the total number of vehicles, independent of their user class Nielsen et al. (1998);
- $\xi$ represents systematic variation of the coefficients (i.e., $\xi_{time}$ and $\xi_{cost}$ are error components);
- $\varepsilon$ represent random variations at the arc level. Gamma-distributed $\varepsilon$’s were used for the present study. The Gamma distribution is reproductive in mean and variance just like the Normal distribution, given that the variance is linked to the mean by a fixed coefficient of variation Nielsen and Jovicic (1999), and it has the advantage of being non-negative.

It is emphasised that the inclusion of the distributed coefficients ($\xi$) improves the models’ ability to describe differences in drivers’ preferences. This results in a more accurate description of their choice of route than given by conventional logit models, where differences in choices are assumed to be caused purely by random variation ($\varepsilon$).

**Data issues**

Estimation of the coefficients in the generalised cost expression was based on SP data. The model has been calibrated on RP data.

**Applications**

As mentioned above the model has served as assignment model in several transport models. One consideration though is whether the complicated model is necessary. It has been seen in the applications that it is very important to have a detailed assignment in a dense network with many competing routes. Furthermore, it could be important to allow for congestion effects and multiple-users classes. On the other hand, if these effect are not important is might be more effective to user a simpler assignment procedure.
13.4.3 Toll road in Eindhoven

Keywords: operational, demand model, regional, toll

Around the west side of the city of Eindhoven, half of a ring has been created as motor highway. At the eastside of Eindhoven, there is currently not a ring road. Therefore, the traffic with an origin or destination at the eastside of Eindhoven has to use the inner city ring or different other short cuts at secondary roads. This leads to unnecessary use of the main road in the city of Eindhoven.

Objectives
In this toll, study two network scenarios for the construction of a eastern ring road (a 2x2 motor highway in tunnels) have been investigated:

- A short variant where the northern tunnel segment starts at the A50/A58 and the southern tunnel segment is connected with the A67;
- A long variant; this is the short variant with an extension at the south side between A67 and A2.

In Figure 13.4, the long network scenario has been shown.

Figure 13.4: Long network scenario

The new motor highway will become a toll road. Five toll alternatives have been defined, each with different toll payment locations. Within each toll alternative, several price levels have been defined to investigate the non-linear effects.

Methodology
In this toll study, use has been made of the static traffic model of the region of Eindhoven. The base of this regional model is a multi-modal system for the total region, which consists of 20 communities. The toll scenarios have only been calculated with the model for car and
trucks, where trucks are split up in light goods vehicles (LGV) and heavy goods vehicles (HGV). In this study, only the route choice effects have been considered. Other behavioural effects like mode choice, departure time choice, destination choice, or the number of trips have not been considered. In toll studies in Scandinavia and France it has been shown that these behavioural aspects are negligible expect for

The model describes the following periods:

- Morning peak (07.00-09.00 hour)
- Evening peak (16.00-18.00 hour)
- Rest of the day (18.00-07.00 hour and 09.00-16.00 hour).

In both peak models, a capacity restraint multi-user class assignment has been applied, containing junction modelling. To assign the cars and trucks at the same time in a capacity restraint assignment, it is necessary to take into account that trucks use more capacity than cars. Therefore use has been made of the PassengerCarEquivalentUnits (PCU). The PCUs that have been used for car, LGV and HGV are respectively 1, 1.5 and 2.5. The model for the rest of the day is assigned with the stochastic Burrell-method.

To calculate the revenues for each alternative a macroscopic dynamic assignment model is used. Therefore, the 2-hour peak OD matrices have been split up in 8 quarters of an hour. Apart from costs, also comfort, guaranteed travel time and status are important. This is the reason that apart from values of time also willingness to pay has been taken into account.

**Data issues**

The following factors for VoT and WTP have been used.

<table>
<thead>
<tr>
<th></th>
<th>value-of-time</th>
<th>willingness-to-pay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>8.28</td>
<td>12.59</td>
</tr>
<tr>
<td>Business</td>
<td>29.79</td>
<td>45.32</td>
</tr>
<tr>
<td>Other</td>
<td>5.78</td>
<td>8.80</td>
</tr>
<tr>
<td>Light goods vehicles</td>
<td>23.13</td>
<td>33.54</td>
</tr>
<tr>
<td>Heavy goods vehicles</td>
<td>39.96</td>
<td>56.74</td>
</tr>
</tbody>
</table>

*Table 13.2: Value of time and factors of willingness to pay (euros per hour)*

**Applications**

The questions that had to be answered in this study were:

- Which toll regime maximises the revenues? Moreover, what are these revenues?
- Which toll regime minimises the total congestion on the network?
- What are the traffic intensities and the effects at the secondary network?
- Which (transportation) possibilities are available to maximise the total toll revenues?

The questions above have all been answered in a clear way with the used traffic model system. Apart from the results in numbers, the graphical presentations of the calculations have
been very useful to understand the outcomes. In general, the results show that if alternative routes are available, then the toll road will be used less. If there is only choice between paying toll or queuing up, the toll road will be used more. This leads to higher revenues, but also to higher traffic intensities on the secondary network.

Figure 13.5 shows, which OD relations make use of the new toll road. It can be concluded that these are mainly travellers with an origin or destination at the east side of Eindhoven.

13.5 Mode specific models

13.5.1 UK national rail model

Keywords: Strategic, rail, assignment, national

The UK national rail model (NRM) is one element of the UK multi-modal modelling package, which is part of the basis for the Government’s Ten Year Plan for transport. The purpose of the modelling package is to assess the impact of various transport policies. Consequently, the national rail model is a strategic model illustrating effects of policy changes or changes in rail services to demand differentiated by corridors and conurbations.

NRM includes five key elements: A demand model, an assignment model, a user interface, a fares model, and aggregation modules. The latter converts matrices from the aggregated demand model to the detailed level of NRM and generalised costs from NRM to the aggregated model elements. The model includes 1328 zones, the entire rail network and all stations.

The rail demand model produces detailed rail demand matrices (by zones and directions) disaggregated by purpose, car ownership, and time periods. The input for the model is aggregated matrices from other elements (including mode choice) of the modelling package.
The rail demand model is the core part of NRM. In the model, the rail demand matrices are assigned to the rail network producing passenger loads on individual routes and lines. Furthermore, the model produces total passenger kms as well as generalised costs, which are used in the aggregated demand models. The generalised costs include in-vehicle time, wait time, access/egress time, fare, crowding, and interchange.

The assignment is carried out in EMME/2 and is thereby based on the theory of optimal strategies formulated by Spiess and Florian (1989). A strategy can be formulated as: Take next train on line 1 or 2, if line 1 is taken then exit at station Y, otherwise take line 2 to station Z and transfer to line 3 or 4 for station Y. This way it is assumed that passengers’ route choices are based on the information available at stations.

A number of parameters in EMME/2 are set specifically in relation to NRM in order for the model to include, e.g., capacity restrictions. First of all the journey time is made dependent on the amount of traffic by multiplying the ‘free flow’ journey time with a crowding factor. This factor is 1 when the number of passengers is below the number of seats in the train, and increasing with increasing numbers of passengers depending on the number of seats and areas for standing.

EMME/2 is then used in an incremental assignment. In the first iteration x% of the demand is assigned to the network based on ‘free flow’ journey times. In following iterations crowding factors are calculated, journey times are adjusted and another x% of demand are assigned according to weighted averages of journey times. The iterations end when all demand is assigned to the network.

The capacity used for calculating the crowding factor is based on the frequencies of individual lines and the capacity of the rolling stock. In addition, the calculation of waiting times is based on frequencies with adjustments to include effects for long headways. The effect of correspondences in timetables is included in boarding times that express the disadvantage of transferring. The boarding time is calibrated for each station individually.

There is a specific user interface for NRM making it possible to change settings relevant for the rail model. Changes can be made to service frequency, stopping pattern, rolling stock, run times, and fares. Other more general settings like population, level of income, etc., are set in other elements of the model package. The user interface does not allow changes of the network. Instead, the network includes lines and stations currently in use or under consideration for implementation in the next 20 years.

The fares model provides a representation of rail fares on a point-to-point basis. Here fares may differentiate by time period and ticket type. The fares model includes different approaches for the national rail and for the London Underground. For the national rail, fares are related to the distance travelled with the possibility of making local adjustments through geographical indicators. For the London Underground fares are related to the existing fare zonal system.
13.5.2 MPL Katowice Airport demand model

Keywords: forecast demand model, regional

Traffic forecast based on the identified demand model, in conditions of economic transformation and market conditions changes, which result from a liberalisation of transport, is not sufficient. An inapplicability of demand volume operated by the individual airports and the potential of their hinterland are additional problems.

Especially in the case of Katowice Pyrzowice Airport, the regional airports are characterised by demand operation below the hinterland potential. This is a domination effect of the central airport that has concentrated the service of national carrier (PLL LOT assumed that this airport will be a hub) in conditions before the air transport market liberalisation.

That is why in case of demand modelling a more elastic approach in this kind of market conditions is necessary. The realisation of forecast purposes is a very important issue - determination of final demand values in case of the general plan to enable the planning of airport development. This approach has been used at International Airport Katowice in Pyrzowice.

**Objectives**
The general objective of the transport model was the evaluation of the development tendency in the range of passenger and cargo traffic as well as air operations until the year 2021.

Simple methods of trends approximation (to establish the minimal forecasts) and elements of econometric modelling (to establish potential demand on the airport impact area) have been used in forecast of air traffic increase at MPL Katowice. Polynomial function of trend has been the basis of forecasts - it was a fourth degree polynomiun.

Forecasts of the passenger number that use air transport has been made in two stages: Firstly, market potential of the air transport service on the area operated by MPL Katowice on the basis of assumptions concerning per capita gross domestic product (GDP) increase in Poland has been designated. Next, the forecast of passenger traffic operated by MPL Katowice has been prepared.

**Methodology**
Forecasts of air traffic development in the area of MPL Katowice for the years 2001-2021 has been based on the comparison of transport activity in Poland and some other European countries. It was assumed that increase of per capita GDP will increase air traffic demand (according to statistic regularity that depends on the relationship between gross domestic product and transport volume) to analogical value, which has been noted in compared countries of Western Europe.

Moreover it has been assumed that the liberalisation of the air market will cause additional increase of air traffic - also thus demand increase outside Poland (15% increase until 2021 has
been assumed on the basis of first results of the liberalisation that were observed in Western Europe).

Estimated transport activity has been converted into passenger number and increase of transport activity has been spread out over years 2004-2021 according to the following principle: until 2003 7.5% increase, then according to evenly divided accruals for the years 2004-2021, which will cause that the growth rate will annually decrease to 5% in 2018.

Fourth degree polynomial function has been used to demand dividing into particular years of the forecast. Only traffic to and from the operation area has been considered in the calculations - potential transit traffic has not been considered.

Potential demand volume has been estimated for two definitions of MPL Katowice impact area:

- nearer hinterland inhabited by 4 250 000 people (this corresponds approximately to population numbers within 60 km radius from the airport),
- broader hinterland inhabited by 7 900 000 people.

It has been assumed in forecasts that inhabitant numbers on the area of the airport influence will not change.

**Data issues**

The model of demand for airport services can be used in case of the airports, which are in conditions of economy transformation - by incomplete data and dynamic market changes. The demographic forecasts for area of Śląskie Province (especially for the cities of Katowice Agglomeration) prepared by the Central Statistical Office were used in forecast of air transport demand.

The main assumptions of demand model: forecasts based on predicted GDP increase and connected with it air traffic as well as the increase caused by the liberalisation of the air transport market.

Predicted development in the range of freight transport (cargo) and air operations has been based on the forecast of passenger traffic increase. Currently volume of cargo traffic and air operations have been extrapolated according to average forecast for passenger traffic.

**Applications**

The model has been used in the feasibility study „General plan of the Airport in Pyrzowice with the conception of the Airport area functional structure” (contracted by Marshals’ Office of Śląskie Province).

On the basis of the study, transformation of military area, handing over of this area to GTL and planning of airport growth have been started. Model has permitted to successful designing of airport development and growth of the surroundings.
Currently (in sixth year since the forecasts based on the model has been made) traffic in Katowice Pyrzowice airport is higher than prepared traffic forecasts, but also higher than forecasts of airport hinterland potential increase. These forecasts are much closer to actual data for year 2005 than in case of British Aerospace and POLCONSULT calculations, which use different demand models. Smaller forecasts mistake of described model has been made in case of cargo traffic and air operations.

Forecasts mistakes has been caused by increase of the absorptive of air transport in conditions of stronger influence connecting with liberalisation (market entry of low-cost carriers from outside of current „players” group observed in European Union). This has caused faster increase of supply as a result of strong increase of emigration for economic reasons from Poland to Great Britain and Ireland).

13.5.3 PUTD, Public Urban Transport Demand model

Keywords: demand model, public urban transport, tickets sales

Identification of demand for public urban transport service is difficult in conditions of dynamic, mass displacement. Demand „notice” is simple only in case of specific distribution systems (based on electronic cards that demand double „punching” by enter and before leave a vehicle). These systems are cheaper, but they are uncomfortable for passengers and they do not give precise information about the demand.

Evaluation of demand for the public urban transport services in the cities is conducted in these conditions with a use of traffic surveys or on the base of ticket sale figures. In the first case the structure of demand volume and passenger flows can be described but it is labour and time-consuming. Demand estimations on the basis of the ticket sale figures permit only to transport volume description, but it is easy to conduct and cheap.

It is necessary to use some assumptions such that the base of demand estimations is a communication behaviour model, because tickets sale does not correspond directly to communication behaviour. It is necessary to make assumptions or conduct fragmentary statistical research in order to estimate number of journeys.

Objectives
Estimation of the demand for urban public transport demand based on ticket sales was the main objective of the model. The range and strength of a downward trend in demand and the necessity of adjusting activities using marketing instruments and transport policy was addressed to the public transport operators.

Methodology
The following assumptions have been used on demand estimation in the model. Single-use (occasional) ticket sales correspond to passenger number in a particular period without adjustment. Correspondence tariffs and so-called bilateral tickets (two journeys of reduced tariff can be realised) – in this case estimation of transport value needs a conversion of sale figures to number of journeys. The following formula (on the basis of data about monthly
ticket sales proportions in 2000) has been used in evaluation of passenger number (passenger journeys) with double punching tickets:

\[ \text{Passengers} = \frac{2 \cdot \text{sale}}{2 - 0.4625} = \frac{2 \cdot \text{sale}}{1.5375} = 1.30081 \cdot \text{sale} \approx 77649480. \]

The volume of journeys on the basis of monthly tickets have been estimated on the base of constant rate of journeys number with the particular type of ticket – this rate has been adjusted to local conditions. The following rates have been used in the model: 67.4 for bus ticket and 57.9 for bus-transport ticket. The volume of journeys estimated on ticket sale figures has been corrected about number of free transport and „fare dodger” – based on available statistical researches.

Estimated volume of passenger traffic determines demand volume for public urban transport services. A trend function was determined based on research conducted over a longer period. The future demand volume was forecasted by the extrapolation of this trend function. This function can be presented in two variants of forecasts: minimum and maximum. This approach has been used in estimations of transport demand made in the model, where trend function has a form of pessimistic and optimistic scenario of forecasts (see Figure 13.6).

Figure 13.6: Forecasts of urban public transport demand based on ticket sale

Regarding internal substitution of ticket offer, the method of demand tendency estimations could not be replaced with ticket sale trends. This is the reason why the modelling approach
that uses the observed communication behaviour (concerning especially journeys by monthly
tickets holders) is most suitable.

**Data issues**
The main data input comes from the special surveys on the number of journeys at specific
routes as well as on the number monthly ticket sales.

**Applications**
The model has been used in activity practice of the public transport organisers in the cities of
Śląskie Province - in the Municipal Transport Union of the Upper Silesian Industrial District,
in Katowice and Association of Commune Union in Jastrzebie.

In defined conditions the model can be used without limitations – with reservations to assume
longer than monthly periods of tickets sale figures measure (ticket are bought sometimes in
advance booking, there are also time difference between transport organisers leave and actual
volume/amount of ticket sale to passengers).

Model of demand based on ticket sale figures can be used in estimation of transport volume
and can be used in transport forecasts. The main area of the model use is local transport
policy.

**13.6 Integration of model levels**
This section will give some examples on integration of model levels.

**13.6.1 TRANS-TOOLS**

**Keywords:** EU-level, integration, linking, GIS

**Objectives**
This example emphasises the use of ArcGIS in the TRANS-TOOLS Transport Model created
by an international consortium for the European Commission (see Nielsen, 2006). The model
describes passenger as well as freight transport in Europe with all medium and long distance
modes (cars, vans, trucks, train, inland waterways, ships, and air transport).

ArcGIS was not only used for combining, improving, and quality control of data, but by using
the Geoprocessing Framework also as the backbone for the model complex itself. This
includes a regional economic model, freight demand and trade models, a freight logistic
model, passenger demand modelling, an airport choice sub-model, network assignment
models for the different modes, and impact models for economics, safety, environment, etc.

**Methodology**
Figure 13.7 below provides an overview of the main model, as it is designed in the ArcGIS
model builder (Muck-up). There is also a feedback mechanism in the model, that secures that
the travel times from the network models influence transport demand and thereby the total
transport volumes. Transport flows then influence the assignment and thereby congestion in
the network. As ArcGIS 9.1 did not include possibilities for loops in Model Builder, this was done by scripts. This was later replaced in ArcGIS 9.2.

**Linking models**
The resulting overall model system is more complex than the muck up indicates. This is mainly because 1) the freight and passenger models include a number of sub-models, 2) the assignment models are different for each mode, and 3) the air model includes choices of airports and mode chains.

Furthermore, it is necessary with a number of data conversion steps (some of which were implemented directly by ArcGIS Geoprocessing framework). This includes disaggregation of flows from the economic model to the transport models’ and vice versa aggregation of transport costs and times for the economic model.

The economic model and trade model work on monetary values (e.g., Euro), while the remaining freight models work with freight volumes (Tonnes). These are then remodelled to truck units before the assignment. Similarly passengers are remodelled to passenger car units before assignment. A further complication is that trips are split up into rush hours and non-rush hours before assignment, and that local road traffic is also assigned onto the network.
Figure 13.7: ArcGIS ModelBuilder Muck-up of the overall model system

Data issues
The preconditions for the project were that it should utilise (reuse) data from previous modelling projects that have been made for the European Union (EU). These data sets were anticipated to have been quality controlled in prior projects. However, transferring the data to ArcGIS and quality controlling these in a GIS-environment soon revealed many problems and bugs in data. In addition to this, the assignment modelling tools revealed further data problems, especially concerning network connectivity.

Applications
Some clear innovations obtained from TRANS-TOOLS were:

- New set up of a demand/supply model;
- Intermodality for passenger/freight (as National and European transport policies promote intermodality through different measures);
- Inclusion of intercontinental flows (mainly for freight), as some models do not cover this segment;
Full coverage of Central and Eastern Europe (Accession Countries and the countries at the borders of the enlarged European Union);

Integration of the New Member States at a level similar to those of EU15 (former member countries);

Feedback infrastructure development economy (as the question of indirect effects in the economy and on network level is important, especially where investment has a substantial influence - notably for Accession Countries);

Logistics/freight chain explicitly included;

Coupling method with local traffic in order to address the effect of congestion on long-distance traffic;

The consortium provided access to all relevant experience concerning EU and national modelling;

A software approach was chosen that resulted in a software modelling tool on network level.

The homepage of the project (http://www.inro.tno.nl/transtools/Consortium.htm) describes the consortia and background in more detail.

13.6.2 Public Transport forecasts in the Euregio Meuse – Rhin

Keywords: operational, demand model, regional, public transport

The Euregio Meuse-Rhin (EMR) (province of Limburg and Liege including the German-speaking community in Belgium, the region of Aachen in Germany and the south part of the province of Limburg in the Netherlands) has the ambition to position and develop itself more as one region. One of the key elements is a well functioning traffic and transport system. The ‘Euregional Public Transport Platform’ is meant to improve the cross-border bus and train connections for the Euregional transport, which also delivers a contribution to the transeuropean high-speed train. For strategic reasons EMR needed a quantitative build public transport forecast to calculate the impact of different scenarios. The study has been developed by Arcadis (Belgium), HHS (Germany), and Goudappel Coffeng (the Netherlands)

Objectives
The base of this model is a classical four-step demand model. The base of the model was the regional model for the province of Limburg in the Netherlands. This model is in use for general assessment of transport projects in the province.

Methodology
The EMR model is a multi-modal system that describes the passenger trips for car, public transport, and bicycle. In this study, the main focus is put in the public transport model. It estimates the number of passenger trips by public transport for an average day in the base year, 2005. Forecasts have been made for the year 2015.
The EMR model predicts demand for travel by five passenger purposes: work, business, shopping, school, and other. The EMR model is divided in 1,324 zones, where 970 zones are in the study area.

The trip distribution and mode choice is determined by a multi-modal gravity model.

Special aspects, which have been tackled in developing the model, was the fact the crossing boarder trips by public transport are difficult to model, because:

- The flows are small;
- Crossing boarder behaviour is very different from national behaviour for several purposes, especially school;
- Little amount of data of current use of the public transport network was available.

Data issues
The main data input comes from the national household-based travel survey in the Netherlands.

Specific attention has been paid to the definition of the socio-economic variables because the data come from three countries. Adjustments were needed in definitions to construct a set for the total study area.

Applications
Eight scenarios have been calculated with the EMR model (2 socio-economic dimensions and 4 public transport network dimensions).

The most important output for each scenario is:

- Number of passengers for all public transport lines in the study area;
- Number of passengers for the crossing boarder relations;
- Number of passenger boarding and alighting at each train station and bus stop in the study area;
- Compressed OD matrices by community.

Based on the outcomes of the scenarios an advise were written in which recommendations are made to which policy measures should have the highest priority. Separation has been made to policy measures for the short term and the long term and to effectiveness and feasibility.
# 14 Vocabulary

<table>
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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AADT</td>
<td>Annual Average Daily Totals</td>
</tr>
<tr>
<td>BRBT</td>
<td>severance and perceived risk</td>
</tr>
<tr>
<td>$c_i$</td>
<td>Cost of alternative i</td>
</tr>
<tr>
<td>C/B</td>
<td>Cost-benefit ratio</td>
</tr>
<tr>
<td>CBA</td>
<td>Cost-benefit analysis</td>
</tr>
<tr>
<td>CGE</td>
<td>Computable general equilibrium</td>
</tr>
<tr>
<td>CIUF</td>
<td>Conditional indirect utility function</td>
</tr>
<tr>
<td>CPA</td>
<td>Classification of Products by Activity</td>
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<tr>
<td>CPI</td>
<td>Consumer price index</td>
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<tr>
<td>CVM</td>
<td>Contingent valuation method</td>
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<tr>
<td>d</td>
<td>Distance</td>
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<tr>
<td>$D_j$</td>
<td>Destination zone j</td>
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<tr>
<td>DTA</td>
<td>Dynamic traffic assignment</td>
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<tr>
<td>$\varepsilon$</td>
<td>Statistical noise</td>
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<tr>
<td>GDP</td>
<td>Gross domestic product</td>
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<tr>
<td>GEV</td>
<td>Generalised extreme value</td>
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<tr>
<td>GIS</td>
<td>Geographical information system</td>
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<tr>
<td>GLS</td>
<td>Generalised least squares</td>
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<td>GNP</td>
<td>Gross National Product</td>
</tr>
<tr>
<td>HGV</td>
<td>Heavy Goods Vehicles</td>
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<tr>
<td>HPM</td>
<td>Hedonic pricing method</td>
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<tr>
<td>I</td>
<td>Income</td>
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<tr>
<td>I/O</td>
<td>Input-output</td>
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<tr>
<td>LBT</td>
<td>Air pollution nuisance</td>
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<tr>
<td>LGV</td>
<td>Light Goods Vehicles</td>
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<td>LL</td>
<td>Log likelihood</td>
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<tr>
<td>LoS</td>
<td>Level of service</td>
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<tr>
<td>LUTI</td>
<td>Land-use transport interaction</td>
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<tr>
<td>MCA</td>
<td>Multi-criteria analysis</td>
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<tr>
<td>MDC</td>
<td>Multi-dimensional comparison/analysis</td>
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<tr>
<td>ML</td>
<td>Mixed logit</td>
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<tr>
<td>MLE</td>
<td>Maximum likelihood estimation</td>
</tr>
<tr>
<td>MNL</td>
<td>Multinomial logit</td>
</tr>
<tr>
<td>MNP</td>
<td>Multinomial probit</td>
</tr>
<tr>
<td>NAI</td>
<td>Noise annoyance index</td>
</tr>
<tr>
<td>NMS</td>
<td>New Member States (but also Dutch NMS (National Model System))</td>
</tr>
<tr>
<td>NPV</td>
<td>Net present value</td>
</tr>
<tr>
<td>NST</td>
<td>Nomenclature uniforme des merchandises pour les Statistiques de Transport</td>
</tr>
<tr>
<td>NST/R</td>
<td>Revised NST</td>
</tr>
<tr>
<td>NUTS</td>
<td>Nomenclature of Statistical Territorial Units</td>
</tr>
<tr>
<td>$O_i$</td>
<td>Origin zone i</td>
</tr>
<tr>
<td>OD</td>
<td>Origin-destination</td>
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<tr>
<td>OLS</td>
<td>Ordinary least square</td>
</tr>
<tr>
<td>p</td>
<td>Price</td>
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P Probability
P/C Production-consumption
PCU Passenger Car Equivalent Units
PT Public transport
Q Link capacity
R² Mean squared error
RA Risk analysis
RUM Random utility maximisation
SCGE Spatial computable general equilibrium
SITC Standard International Trade Classification
T_{ij} Number of trips between origin i and destination j
t Travel time
{t}_0 Free-flow travel time
TEN Trans European Network
TCM Travel cost method
U_i Utility of alternative i in a discrete choice
V Link flow
V_i Observed utility of alternative i
V_{oT} Value of time; in some literature replaced by VTTS for value of travel time savings
W Indirect utility function
WTP Willingness to pay
x Continuous goods
PART 4: Best practice examples
SIXTH FRAMEWORK PROGRAMME

FP6-2004-SSP-4

Scientific Support to Policies (SSP)

“Integrating and Strengthening the European Research Area”

Acronym: MOTOS
Full title: Transport Modelling: Towards Operational Standards in Europe
Proposal/Contract no.: TREN/06/FP6SSP/S07.56151/022670
Start date: 1st June 2006
Duration: 12 months

D2.2 MOTOS Best practice examples

Document number: MOTOS/D2.2/PU/v2.0
Date of delivery: 30th of March 2007
Work package: WP2
Deliverable type: Public
Lead participant: CTT, DTU

Abstract:
The report is delivery 2.2 in work package 2 of MOTOS. It contains best practice examples on economic, freight, demand, and assignment modelling in transport models.

Keywords:
MOTOS WP2, state of the art, best practice, transport modelling
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1 Introduction

This report provides an overview of state of the art and best practice in transport modelling in Europe. It is the main delivery of work package 2 (WP2) of the MOTOS project.

1.1 The MOTOS project

The MOTOS project aims at the integration of transport modelling in the enlarged union. The high-level goal of MOTOS is:

*To support transport policy in Europe, by defining common good practice principles for national and regional transport modelling that satisfy immediate needs of model developers in the New Member States and contribute to the establishment of a standardised approach for transport modelling in the European Union.*

The project emphasises the importance of user needs and best practice as influential factors in the process of improving the general standards in modelling.

1.2 WP2 of MOTOS

The purpose of WP2 is to produce reports on state of the art and best practice within transport modelling that can form the basis for a handbook on best practice in transport modelling. The output should describe characteristics of best practices for different types of transport modelling in the main areas freight demand, passenger demand, economic, and assignment modelling. Furthermore, the output should focus on how different models are linked, e.g., how regional models link to a national model.

The WP2 of MOTOS has two deliverables:

D2.1 Report on state of the art, best practice examples, and linking of models
D2.2 Report on common best practice principles

The two reports, D2.1 and D2.2, have been structured so that the first gives an overview of state-of-the-art modelling and linking of models, together with a summary of best practice examples. The second report describes common best practice principles and gives detailed descriptions of the examples. Hence, the second report can be seen as an appendix of the first.
1.3 The structure of this report

This report will provide an overview of best practice applications in European transport modelling. The report divides the best practice examples into 6 groups: freight, passenger demand, economic modelling, assignment, mode specific models, and integration of models.

Chapter 2 discusses the concept best practice from a general point of view.

Chapter 3 provides two examples on freight modelling: a EU-level example (TRANS-TOOLS) and a national level example (the Dutch SMILE).

Chapter 4 gives six examples on passenger demand models. The first illustrates the role of land use in transport models (MEPLAN and TRANUS). The second is an example of a demand model at national/regional level (SAMPERS). The third describes a trip-based regional model (Pilsen Region), while the fourth describes a tour-based regional model (OTM, Denmark). The fifth illustrates a prototype of activity-based modelling and is the only example outside Europe (Boston). The sixth and last example of demand is a multimodal transport and impact model (TRANSURS, Hungary).

Chapter 5 includes two examples showing the role of economic modelling in transport modelling. The first example is CGEurope in TRANS-TOOLS and the second is on linking of economy, energy, and environmental aspect (GEM-E3, EU).

Chapter 6 includes three examples on assignment. The first includes a timetable-based model for public transport with focus on regularity issues (DSB rail model, Denmark). The second on multi-class road assignment with intersection delays (Copenhagen, Denmark), and the third on assignment and toll assessment (toll road in Eindhoven).

Chapter 7 gives three examples on mode specific models: a rail model (UK national rail model), an airport model (MPL Katowice Airport model), and public transport model (PUTD, Polish urban transport model).

Chapter 8 has two examples on linking of different level in a modelling context. The first example is on linking using GIS at a European level (TRANS-TOOLS). The second example is on linking at a regional level (Euregio Meuse – Rhin, Germany).

Finally, Chapter 9 contains a list of literature.
2 Best practice experiences

Best practice modelling has to address at least three important aspects in any concrete application: objective, data, and validation.

Central to any applied model is the planning context. This makes the objectives and requirements behind the model very important. Planning is usually a process that starts with an analysis of possible deficiencies of the current transportation system or transport policy. It is followed by a design process that consists of development of a solution, determination of impacts, evaluation of impacts, and analysis of deficiencies. This process continues until a satisfying solution is developed that meets the demand of the planning objectives.

The process is often shared between a user and a transport planning tool. While the planner successively improves the design based on the current state or policy objectives, a computer model of the transportation system determines future impacts of the solution. The aim of the modelling process is model-based preparation for decision-making.

In the design of a traffic model, the modeller needs to consider level of detail, level of complexity and time horizon. These three aspects are discussed in Chapter 3 of the D2.1 report. Here they serve to categorise the examples.

Generally, the more time and cost used for collecting data, design and development of a model the better the description of current traffic conditions. Thus, the level of detail is typically a trade-off between costs for the study and accuracy. On the other hand, detailing a model more than necessary would be a waste of money. Therefore, the level of detail should be targeted to the purpose.

For instance, many traffic models overlook induced traffic despite empirical evidence of the importance of this. This ignorance may be criticised and results even disregarded by decision-makers afterwards. Thus, it is crucial to outline the most likely impacts of the plan proposal and then design the model according to this.

How precise can the models perform? Do we believe the results of the models? These two questions are very important and underline the importance of validating models. If nobody believes the results then the model has no value. One thing is to report all the statistical tests and the theoretical understanding of the various models, but these measures are still irrelevant if the model cannot be proved to provide reliable answers to the questions they are developed to answer. This highlights the importance of professional experiences and judgements in application of transport models. Section 4.4 of the D2.1 report addresses this issue in more detail.
Together with examples of best practice to heighten practice, another approach would be to look at existing national manuals on good practice in transport modelling. A leading example here is the valuable information made available by the British Department for Transport (DfT). The document on Transport Analysis Guidance¹ (TAG) gives a clear description of important concerns in applied modelling. This probably exists in other countries as well. However, as it is the case for the Danish guidance on cost-benefit analysis, language is often a barrier. Below we mention some sites with guidance concerning transport modelling.

Internet references:

- [www.dft.gov.uk](http://www.dft.gov.uk)
- [www.bts.gov](http://www.bts.gov)
- [www.fhwa.dot.gov](http://www.fhwa.dot.gov)

¹ [www.webtag.org.uk](http://www.webtag.org.uk)
3 Freight best practice

3.1 A EU-level freight model, TRANS-TOOLS

Keywords: EU-level, freight, logistics

Reference: TNO, Arnaud Burgess

Objectives
The logistic part of TRANS-TOOLS (TNO, 2006) is chosen as a best practice example on freight modelling. The working of the logistic module is based on SLAM, a module, that can be appended to the SCENES model. SLAM makes it possible to evaluate the impacts of changes in the logistic and transport systems within Europe on the spatial patterns of freight transport flows through changes in the number and location of warehouses for the distribution of goods.

![Flow chart of the logistic module in TRANS-TOOLS](image)

Figure 3.1: Flow chart of the logistic module in TRANS-TOOLS
Methodology
The logistic module produces output that is to be used in the assignment model and in the economic model.

Output for the assignment model
For the assignment model the logistic module will produce unimodal transport matrices (Origin, destination, mode, NSTR, tonnes, vehicles).

Output for the economic model
The economic model needs generalised and monetary costs per origin, destination, and commodity type. These costs can be computed from the assigning process (the logsum of the mode costs per segment). The origin and destination will be on NUTS 2-level and are the origin and destination of segments of a chain. The costs will be in €/ton.

Calibration of the Logistic Model
The calibration of the logistic module was carried out in two steps:

- Calibration of the region scores.
- Calibration of the transport volumes and the modal split.

Data issues
Two data sources were used for the calibration. The first is the number of employees per region in 2000 (Eurostat). This statistic is used as an indicator for logistic activities. This indicator is used because data about indicators like the throughput in distribution centres is not available. The number of employees per region is the best possible alternative, but not a very good indicator for logistic activities. This implies that the performance of the logistic module can be improved when better data become available.

The second source is the number of tonnes transported between two regions by each mode (ETIS-BASE). Using these data for the calibration has a small disadvantage, because ETIS-BASE is also used as input for the logistic module. Obviously, the modal split after running the logistic module will be quite similar to the modal split in ETIS-BASE. However, this is not really a problem, because the aim of the logistic module is to determine the usage of distribution centres and not to determine the modal split. The freight modal-split model of TRANS-TOOLS determines the modal split on most of the relations and the logistic module only completes this for transport segments with unknown modal split. Using ETIS-BASE for the calibration assures that no big changes in the modal split occur.
Applications
In the first step of the calibration, the region scores are calibrated. The region scores are used for ranking the regions according to attractiveness for logistic activities. The region scores are build up from three components: economic activity, centrality, and flexibility.

The scores for these three components are multiplied by parameters that indicate their importance added up. This results in the region score:

\[ \text{sc}_\text{REG}(N_{str}) = \text{imp}_{EA}(N_{str}) \cdot \text{sc}_{EA} + \text{imp}_{CENT}(N_{str}) \cdot \text{sc}_{CENT} + \text{imp}_{FLEX}(N_{str}) \cdot \text{sc}_{FLEX} \]

- \( \text{sc}_{\text{REG}} \): region score
- \( \text{sc}_{\text{EA}} \): score economic activity
- \( \text{sc}_{\text{CENT}} \): score centrality
- \( \text{sc}_{\text{FLEX}} \): score flexibility
- \( \text{imp}_{\text{EA}} \): importance economic activity
- \( \text{imp}_{\text{CENT}} \): importance centrality
- \( \text{imp}_{\text{FLEX}} \): importance flexibility

The region scores are computed for the five commodity groups (see Table 13.1) for which logistic activities are the most relevant. The ranking of the region scores for each of these commodity groups is compared to the ranking of the regions according to the number of employees per region. It turned out that the correlation coefficient for all five commodity groups is the highest in the case where the importance of economic activity is equal to 1 and the importance of both centrality and flexibility is equal to 0. This implies that the likelihood of a region being used as a distribution centre is fully determined by the economic activity. With this conclusion, it must be kept in mind that the number of employees is not a very good indicator for logistic activities.

This explains why the correlation coefficients are not very high. The parameter settings of \((1, 0, 0)\) for importance of economic activity, centrality, and flexibility for each commodity group are used in the next step of the calibration. These parameters can be found in the table ‘Nstr’ of the database ‘Logmod.mdb’. These parameters can only be changed by experienced users and therefore it has been decided not to make these parameters available for every user of TRANS-TOOLS.

<table>
<thead>
<tr>
<th>N_{str} Code</th>
<th>N_{str} Name</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Agriculture Products and Live Animals</td>
<td>0.554</td>
</tr>
<tr>
<td>1</td>
<td>Foodstuffs and Animal Fodder</td>
<td>0.759</td>
</tr>
<tr>
<td>5</td>
<td>Metal Products</td>
<td>0.589</td>
</tr>
<tr>
<td>8</td>
<td>Chemicals</td>
<td>0.647</td>
</tr>
<tr>
<td>9</td>
<td>Machinery, Manufactured Articles, Misc.</td>
<td>0.727</td>
</tr>
</tbody>
</table>

Table 3.1: Correlation coefficient between region rankings
In the second step, the logit parameters of the nested logit model were determined. It has been decided to fix the probability for each chain type in this stadium to the following settings:

- Direct transport: 0.5
- Transport through a European distribution centre: 0.2
- Transport through a national distribution centre: 0.25
- Transport through a European and national distribution centre: 0.05

This implies that the logit parameter for the choice of chain type is not used. The fixed probabilities can be found in the table ‘Chaintype’ of the database ‘Logmod.mdb’. These probabilities can also be changed by experienced users only and are therefore not available for every user of TRANS-TOOLS.

The logit parameters for the chain choice and mode choice were varied to find the parameter settings with the best fit:

- Logit parameter chain choice: 0.00005.
- Logit parameter mode choice: 0.005.

These parameters can be found in the table ‘Pars’ of the database ‘Logmod.mdb’ and can also only be changed by experienced users.

A comparison between the number of tonnes transported through distribution centre regions (computed with these parameter settings) and the number of employees per region resulted in a correlation coefficient of 0.373. A comparison of the number of tonnes transported between each region by each mode (computed with these parameter settings) and similar figures obtained from ETIS-BASE shows a very good fit (correlation coefficient of 0.997). As explained before, this was to be expected.

Finally, the modal split computed with these parameter settings is respectively 74.3 %, 7.3 %, 3.3%, and 15.1% for the modes road, rail, inland waterway, and sea.

It can be concluded that the outcomes of the logistic module show a moderate fit with the number of employees per region. This is partly explained by the fact that the number of employees per region is not a very good indicator for logistic activities. The modal split is quite realistic. This indicates that the logistic module produces reasonable results.

However, there are still many possibilities for improving the logistic module of which the most important is the improvement of the data availability about logistic activities. At the moment uniform data about logistic activities are not available for all the EU countries. It is desirable that these data will be collected in the near future in a similar way in all EU
countries. Once these data are available, a more detailed calibration in which more parameters (like the pmt-cells) are calibrated can be carried out.

In the figures below, the output of the logistics model is given; the modal split of intra-European flows and the spatial distribution of logistics activities in Europe.

**Freight modal split**

![Pie chart showing the modal split of freight transportation in tonnes]

**Figure 3.2: Freight modal split (intra-European freight transport in tonnes)**

**Tonnes lifted at distribution centres**

![Map showing tonnage distribution]

**Figure 3.3: Freight modal split intra-European freight transport in tonnes**
3.2 A national freight model, SMILE

Keywords: national, freight, logistics

Reference: TNO, Arnaud Burgess

Objectives

Essential for a model is the notion that developments in freight flow demand are the result of changes in economic structures that create a demand and a supply of goods in specific geographic regions and form the basis for transport flows between regions\(^2\).

The general aim for the SMILE model is to get a better view on future developments in freight flows that use Dutch infrastructure. Therefore, we take two kinds of freight flows into account with separate treatment.

1. Freight flows that relate to the Dutch production and consumption structure (i.e., relationships to and from Dutch production units).
2. Freight flows that use Dutch infrastructure but do not have a direct relationship with the Dutch economy (this includes transit flows using Dutch ports for transhipment and intermodal change only).

The first category of flows is a direct result of the production structure within the Netherlands and the logistic organisation of flows that exists between these production units. The second category holds the same but these have the extra choice possibility of not using Dutch infrastructure and therefore have to be treated differently.

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\(^2\) This section is based upon Tavasszy (1998).
The logistical organisation is defined as the way the goods flows are controlled, both as necessary activities to make production activities possible as well as all the activities necessary to fulfil the demand by customers.

**Methodology**

In general, a distinction can be made between product logistics and transport logistics. Product logistics has to do with the control of good flows from basic products, via inventories and intermediate production activities till the physical distribution of final products to the customers. This is visualised in Figure 3.5. This figure shows that the whole logistic process consists of several repetitious activities involving the basic activities production, inventory, and transport (PIT). Transport logistics involve the optimisation of the organisation of freight flows so that the utilisation of transport equipment is optimised, considering costs and quality elements such as reliability and speed.

![Figure 3.5: Relationship between PIT and Product Logistics](image)

With SMILE, some first steps have been taken to resolve the shortcomings in knowledge about the relationship between production, inventory, and transportation by a three level chain modelling approach. The first level concerns the linkage between manufacturing activities within product chains, the second concerns the modelling of stockholding within distribution chains, and the third relates to the movement and transshipments of...
goods within (multimodal) transport chains. Below we explain how these three levels have been operationalised in the model.

**Production, Sales and Sourcing**
At the first level, make-use tables create the opportunity to set up a production function for each sector (if the sector produces only one commodity group for each commodity). In contrast to the prevailing models of sectoral exchanges of goods, in the SMILE model the conventional input-output modelling approach has been abandoned. The available make-use tables provide a detailed insight into the production factors connected to the activity of each sector, including the commodities that are produced and consumed. By linking production and consumption, product chains can be built that, when combined further, result in production networks.

One of the main features of the SMILE model is the application of these production functions in the assessment of the effects of a change in final demand for one product group on all the others through the production network. This new approach allows tracing, e.g., the effects of a 20% replacement of steel by composites in the car manufacturing industry on the volumes of freight flows. Moreover, the make-use tables are very helpful in establishing the location pattern of both production and consumption.

After having determined the volume and nature of production and consumption at different locations, the spatial distribution of flows between these locations is calculated. This spatial distribution results from the sales and sourcing processes at each location. As trade theory tells us, it is a result of comparative price differences and the resistance of geographical, organisational, and institutional differences that have to be bridged. This part of the model provides the user with the trade relations in the Netherlands.

**Inventory**
The main function of the second level is to link trade relations to transport relations by considering warehousing services. A logistic choice model describes distribution chains. Several configuration options for distribution chains are investigated (see Figure 3.6). These are characterised by the number and location of distribution centres.

![Figure 3.6: Optional distribution structures](image)

**Figure 3.6: Optional distribution structures**
In the choice model, total logistic costs are calculated that account for handling, inventory, and transport costs for homogeneous product categories denoted as logistical families. A survey on product characteristics has been undertaken to support the model with real-life data; its results clearly show the relevance of distribution chains for modelling of freight transport demand. For almost half of the 300 products investigated, the same type of distribution centre (continental, national or both) was in use.

Following the survey, new groups of products and market conditions were identified in which it is reasonable to assume that within these groups logistic choice behaviour is homogeneous. At present logistic families are distinguished using the following product and market characteristics:

- value density (the value of products per m³);
- packaging density (the number of colli per volume unit);
- perishability (the period in which a product is technically or economically usable);
- delivery time (in days);
- shipment size (in tonnes);
- demand frequency.

In aggregate freight transport system modelling, this issue has not received the attention it deserves, particularly if one looks at the ongoing trend of “reconfiguring European logistics systems”. The existing aggregate modelling approaches, which combine production and network modelling, do not represent this second level. Neglecting this level may adversely affect the accuracy of modelled freight flows as well as the policy sensitivity of the model.

*Transportation*

At the third level, a multi-modal network (see Figure 3.7) for 6 modes of transport is available in SMILE. It is a strategic network, which means that only the network structure is modelled. Not all alternative links between regions are visible to the user, but only one representing all alternatives.
Figure 3.7: Multimodal network

The underlying network used for calculations is modelled in analogy with the physical network. The figure above illustrates this network type for three modes. The optimal route in SMILE will be sought for every commodity type, and for every element in the logistics chain. The route choice disutility has a mode specific (see Baumol and Vinod, 1966) weighted cost formulation where a combination is made of the physical distribution costs and time spent during transportation.

The weights that are used are specific per goods type and reflect the opportunity costs of the resource “time” within the entire logistics process. Comparing this model with existing approaches in physical distribution (see, e.g., Goss, 1991; McGinnis, 1989; Jourquin, 1995; Vieira, 1992), the formulation is new within this complex setting (using empirical values for 50 logistical families, reflecting total logistic costs including estimated random preferences).

Data issues
Do we wish to give a forecast for one point in time or do we need information on the growth patterns of system variables? Insight in growth patterns gives insight in the existence of saturation levels and equilibrium mechanisms. Although two scenarios may produce similar results for a specific forecast year, they may show a completely different development in the years before and after the forecast year. The understanding of these dynamics is at least as important as the exact prediction of the levels in the horizon year under study.
Figure 3.8: Simulative modelling approach

Applications
The above stages of production, distribution and transportation form three steps in the calculation process. These are repeated in a cyclical simulation process, as illustrated in the figure above. Each simulation cycle represents a time span of one year; a complete simulation results in time series data related to transport flows and costs. Naturally, the intermediate output concerning economic activities, the exchange of goods, and the logistics service markets are obtained in a similar way and stored in the SMILE database.

The latest update for SMILE to the SMILE+ is that a growth factor approach is applied to a base year matrix. A pivot-point method is applied whereby growth factors are retrieved from the SMILE+ and applied to a detailed base-year matrix.
4 Passenger demand best practice

4.1 Land-use/transport modelling: MEPLAN and TRANUS

Keywords: strategic, land-use/transport, quasi-dynamic, regional markets


The land-use/transport systems MEPLAN and TRANUS have a common origin in research and development within the Martin Centre for Architectural and Urban Studies and in the Centre for Land Use and Built Form Studies, University of Cambridge. During the 1980s, the development of the MEPLAN and TRANUS software systems was conducted within the two firms Marcial Echenique & Partners and Modelistica, respectively. The model systems are based on spatial input-output theory and spatial markets interacting through flows of passengers and freight in the transport systems.

Objectives
The aim of land-use/transport interaction (LUTI) models is to analyse the mutual relationships between location processes and transportation processes. This is achieved by modelling spatial markets (land market, real estate market, markets for goods and services) and their interactions with transport markets. The models normally assume that the transport market represents a fast process that equilibrates with land-use without delay, while the slower spatial markets respond to the transport conditions of the previous period. LUTI models are developed mainly for multi-purpose strategic use.

Methodology
MEPLAN is a software package developed by Marcial Echenique & Partner (now part of WSP Group) that offers facilities to analyse the interactions between economic activities and transport at various levels from the strategic to the local. It is based on the following principles (LT CONSULTANTS, 2004):

- Transport is a derived demand from interactions between activities.
- Transport exerts an influence on the location of activities over time.
- Transport and land-use are treated as markets where the interaction between supply (networks and land) and demand (flows and activities) establishes the price of transport and land.

The model system can be classified as a spatial input-output approach with an endogenously determined pattern of trades affected by the transport flow equilibrium of the previous time period. The system includes a module for economic evaluation of overall costs and benefits and their distribution.
TRANUS is a software package developed by Modelistica (based in Venezuela), that combines a model for activity location and interaction, land-use and the real estate market with a comprehensive multimodal transport model. It can be applied for any scale, from detailed urban to regional and national levels, and from very short-term pure transport projections to long-term strategic studies. Some features of TRANUS (Modelistica, 2007):

- Double purpose: simulation of probable effects of land-use and transport policies and projects and evaluation of these from social, economic, financial, and energy points of view.
- Roots in spatial interaction and discrete choice theories.
- Graphic interface.

The quasi-dynamic structure of TRANUS is the same as the one outlined for MEPLAN: a transport equilibrium is established in every time period and affects the land-use/location developments of the next time period.

The main model interactions and the quasi-dynamic structure of both MEPLAN and TRANUS can be illustrated in two figures, see Figures 4.1 and 4.2 (source: LT CONSULTANTS, 2004).

![Diagram of principal structure of MEPLAN and TRANUS](image_url)
The red (lower) arrow of Figure 4.1 is representing the slow (delayed) impact of transport on land-use, while the blue (upper) arrow indicates the more direct impact of land-use changes on transport. The development over time is more clearly described in Figure 4.2.

More details on the internal steps of the land-use and transport components are outlined in Figure 4.3 (from web site description, Modelistica, 2007). The figure also indicates that TRANUS (and MEPLAN) is relying on economic base assumptions in the sense that externally determined final demand (or “exogenous production”) is the main driving force behind the urban development. Other modelling traditions employed in the modelling framework are gravity (or entropy maximising) models, spatial micro-economic models, discrete-choice models and input-output models.

One aspect of the methodology is that OD matrices are determined in the location part of the models while modal split is handled in the transport part. This means that a certain destination/modal split choice structure is built into the models.
TRANUS and MEPLAN were both applied to more than one European city in the PROPOLIS project (Planning and research of policies for land use and transport for increasing urban sustainability, LT CONSULTANTS, 2004). The main features of the analytical framework are outlined in Figure 4.4. The feedback from indicator modules to land-use/transport models is required to obtain an integrated land-use/transport/environmental analysis but is hardly implemented in the PROPOLIS models (as is clearly shown in a more detailed diagram of the modelling system; see Figure 3.2 of LT Consultants, 2004).

Instead, previously existing land-use/transport models for each one of the seven cities were implemented for analysing a set of policies (both urban specific and jointly specified). The outputs were translated into common data formats for calculating jointly developed sustainability indicators in common format, which were used in an elaborate evaluation and presentation framework.
Another project, where MEPLAN and TRANUS have been implemented is the Sacramento Model Testbed study, Hunt et al. (2001). Three land-use/transport models were calibrated on data for the Sacramento region and the results of policy tests were compared to the results of an existing transport model of the four-step type.

The PROPOLIS project and the Sacramento Model Testbed represent two ways of conducting comparative studies: two models, each applied to more than one city and all cities being different (PROPOLIS) and two models applied to the same city (Sacramento). While the typical comparative study relies on a set of models each applied to their home city, the ultimate set-up would be to compare a certain set of models, each applied to the same set of (more than one) cities. This was attempted in the ISGLUTI study (see Webster et al., 1988).
Data issues
Both the MEPLAN and TRANUS model frameworks are general and synthetic and can be applied in contexts with very different data availability. The minimum requirement is a description of the transport networks, land supply and exogenous demand relating to “basic” industries. All additional information is used only for calibration.

The calibration of the models is a major undertaking. The interactive nature of the models implies that calibration of one part to fit observed values is dependent on the calibration of other parts. If the target data for calibration relate to several time periods, the dynamic version of the whole model must be run repeatedly. Some assistance in the search for parameter values can be provided by the computer software, but calibration is mainly a complicated manual trial-and-error process requiring considerable experience.

In the PROPOLIS study calibrated land-use/transport models already existed in all seven cities (four of which were analysed by MEPLAN: Naples, Bilbao, Helsinki and Vicenza; and two were analysed by TRANUS: Brussels and Inverness). The number of land-use zones equalled the number of transport zones in most cases (varied between 81 and 161). In two MEPLAN applications, the number of land-use zones were considerably smaller than the number of transport zones (Naples: 39 land-use zones and 179 transport zones; Vicenza: 27 land-use zones and 102 transport zones). The transport network data are not explicitly stated for all cases, but the number of road links is of the order 1000-1500 in some of the case studies.

In the Sacramento Testbed study, the models were calibrated using different strategies and different calibration targets. This also led to quite different levels of person trips, vehicle miles travelled (VMT) and average trip distance. The number of zones (land-use and transport) was 65 and the road network contained about 1600 links.

The diversity of applications can be seen as a major strength of the model systems. At the same time, it restricts the transfer of experiences between various applications. Parameter values can vary considerably between very similar applications. According to Hunt and Simmonds (1993), the accumulated experience is largely in terms of concepts, theories, methods, and modelling approaches, rather than in terms of key parameter values.

Applications
Both MEPLAN and TRANUS have been applied in widely different contexts in planning and research. For examples of early applications, see Hunt and Simmonds (1993) and de la Barra (1989). Here the focus will be on the more recent applications reported in the PROPOLIS and Sacramento Testbed projects. PROPOLIS included four MEPLAN and two TRANUS urban implementations in the European context and in the Sacramento Testbed project both model frameworks were applied to the same (American) city. As can be seen from the zonal subdivisions reported above, the applications are of a strategic or sketch planning character.
LT CONSULTANTS (2004) contains analysis of the results (using, e.g., MEPLAN and TRANUS) by imposing a set of common policies (transport, land-use, combinations) on each city. An inter-city comparison concludes the analysis, focussing on similarities across the cities. Such similarities can form the basis for generic conclusions that are likely to be transferable also to other cities. The prevailing trend in the reference scenario (2001-2021) in all cities is declining environmental quality. In most cities also social quality is declining. The impact of policies on some key indicators and on aggregate environmental, social and economic indices is compared over cities. It is clear from these results that pricing policies (fuel tax, cordon toll, parking costs) and combination policies (car pricing combined with public transport policies and land-use policies) can be designed that improve all three urban sustainability dimensions. The results of a multi-criteria analysis (MCA) is shown in Figure 4.5 (LT Consultants, 2004) for the Dortmund case study. The figure also indicates the problematic trend according to the reference scenario. A number of combination policies (711-713) do almost preserve the 2001 environmental and social sustainability while having a positive economic evaluation. Two policies are dominant in either social (219) or environmental (719) terms but have a negative economic evaluation.

The Sacramento Model Testbed study showed that there were considerably larger differences between the results of different models for a particular policy scenario than between policy scenarios for a particular model. This probably was due both to the policy scenarios (fairly modest changes) and to the effort and method of calibration of the different models. In the US Department of Transportation Toolbox Project Sacramento constituted one of the case studies. One of the conclusions on the project web site (USDoT, 2007) is that “Accounting for land use effects can have significant impacts on forecast vehicle-trips, VMT, congestion, and emissions. Travel and emissions impacts were found, in general, to be significantly greater in MEPLAN than in SACMET96 for comparable policy scenarios” (SACMET96 is the state-of-practice transport model used in the study).
4.2 National/regional forecasting system: SAMPERS

Keywords: tour-based, passenger transport, forecasting, international, national, regional

Reference: Lic. Phil. Michael Heen, SIKA – Swedish Institute for Transport and Communications Analysis

SAMPERS, initially developed 1998-1999 on the initiative of a “buyer group”, is a Swedish passenger transport forecasting system on the national and regional levels. International travel is also handled. The system of demand models is tour-based and interacts with equilibrium assignment models. Integration of modelling steps and a user-
friendly interface were key concerns for the new system. The main use is in strategic and tactical infrastructure planning on national and regional levels.

**Objectives**
The new SAMPERS system was designed to replace earlier models, which had been developed separately, to cover all trips, to add new features in demand modelling, assignment and impact assessment, and to provide an integrated and user-friendly system of state-of-the-art models. The model development and estimation should draw on recent data from national travel surveys. The reasons behind the model development are discussed in Widlert (2001) from the perspective of the “buyer group”.

**Methodology**
Nested logit models of passenger transport demand are formulated for:

- International travel to and from Sweden (670 domestic zones, 180 international zones).
- National travel, i.e., trips longer than 100 km (between 670 zones).
- Regional (and local) travel (five regional models with 1000-2500 zones each).

The structure of the various models in terms of the hierarchy of their constituent parts (frequency, tour choice, destination choice, mode choice, time-of-day choice, ticket type choice) is determined in the estimation process. The number of choice levels differs between the three model types. Simultaneous full-information maximum likelihood estimation is applied, if possible.

The following travel purposes are considered:

- International: business and leisure (from Sweden), all purposes (to Sweden).
- National: business and private.
- Regional: work, business, school, social, recreation, and other purposes.

The following travel modes are considered:

- International: car (by road or ferry), bus, train, air, and ferry.
- National: car, bus inter-city train, high-speed train, and air.
- Regional: car as driver, car as passenger, public transport (divided into bus or train), walk, and bicycle.

The main structure of the passenger demand models is outlined in Figures 4.6-4.7 (regional), 4.8 (national), and 4.9 (international).
Figure 4.6: Structure for home-based simple tours in the regional model

Figure 4.6 (Algers and Beser, 2000) shows the structure for home-based simple tours, e.g., trips starting at the home location, travelling to an activity for a certain purpose and returning to the home location. Below the trip/no trip decision in the choice structure one finds in turn mode choice, destination choice and detailed choice of public transport mode (if public transport is chosen as the primary mode). The different choice levels are connected through “logsums”: for instance, in the mode choice part, logsums representing expected utilities from the destination choice are included as explanatory variables.

Figure 4.7 shows the general structure for non-work tours. These can either be of the simple home-based type reported in Figure 4.6 or the combination of a work trip with either a work-based trip to a non-work activity (i.e., starting from and returning to work) or with a stop on the way to or from the work location (i.e., a secondary destination added to the work trip). In this way, some share of trip chaining can be reflected in the otherwise trip-based approach. The model is including links between the various levels in terms of logsums as mentioned above.
The SAMPERS system consists of five regional models (with the structure outlined in Figure 4.6-4.7) for regions with 1.1-2.8 million inhabitants: south, west, southeast, extended Stockholm and north. Some of these regions are much larger than labour market regions. The southern region is extended to Zealand in Denmark. The regional models include 1000-2500 zones, 21000-31000 road links and 20000-47000 transit segments. The structure of the regional passenger demand models were jointly estimated on the total database for all regions. The region specific character was achieved by adjusting a set of specific constants for each region. The access/egress tours to stations/airports in connection with long distance travel are handled as separate components of the regional models.

The nested model structure of the national long distance model of the SAMPERS system is shown in Figure 4.8 (Boser and Algors, 2001). The exact form of the nested structure differs between travel segments: in some cases the position of destination and mode choices are interchanged. The time-of-day and ticket-type choices are modelled for air and rail travel and are linked to timetable-based assignment models for these modes.
Figure 4.8: Nested structure of the extended long distance (national) demand model

The SAMPERS system contains a special module for analyses of international passenger demand. It includes separate models for Swedish citizens travelling to/from Sweden and foreign citizens travelling to/from Sweden. Trips within the Öresund region (Scania and Zealand) are excluded and handled in an extension of the regional model for southern Sweden. The structure of the models for international trips is shown in Figure 4.9 (Algers and Beser, 2000). Route and mode choice models were estimated simultaneously and then used in the estimation of trip frequency. Data from the Swedish travel survey, interviews conducted within the Öresund and Fehmarn Belt studies and OD level-of-service data for all modes were combined.

A separate call for tender concerning the traffic assignment models of SAMPERS resulted in the decision to use the EMME/2 models (equilibrium auto assignment, public transport frequency-based assignment, and long distance time table-based assignment).

Modules for assessment of impacts (safety, emissions, energy, operating, and maintenance costs), cost-benefit analysis and accessibility evaluations make up other parts of the model system.

The methodology of the SAMPERS system is regularly updated (according to decisions taken by the “buyer group”) and new versions are made available to the users.
Data issues
The main data source for estimation of the passenger demand models of SAMPERS is the Swedish national travel survey 1994-1998. For international travel, other surveys in connection with the Öresund and Fehmarn Belt studies were also used. SIKA (Swedish Institute for Transport and Communications Analysis) provided transport system data from the EMME/2 system. Socio-economic data were delivered by Statistics Sweden for the Small Area Market Statistics (SAMS) spatial subdivision.

Applications
The model system is designed for general use in strategic and tactical planning contexts on the national and regional levels:

- Demand effects of new infrastructure or new services (projects, programmes).
- Demand effects of, e.g., income, population, and employment changes.
- Impact assessments: safety, environment, energy, accessibility, regional development, etc.
- Assessment of pricing and regulation policies: taxation, tax deductions, road pricing, area licensing, road tolls, rules for company cars, etc.
SAMPERS is reasonably well documented in English (overview, estimation/calibration/validation of passenger demand models). Other manuals are only written in Swedish. The demand models and the user interface are available in open source code, while the assignment models are licensed products.

The requested flexibility and comprehensiveness of the system made it quite complex with handling of large quantities of data and hundreds of parameters and variables, which must be controlled by users of the system. The owner of the system can define one or several complete set-ups of scenario data (socio-economic, demographic, traffic system and policy variables). The user can copy the default scenario, make changes of the scenario and run a forecast and evaluation. An information control system informs the user (and anybody else interested in the results) about the deviation from the defined base scenario.

Zonal data are stored in an Access database, traffic system data are stored in the EMME/2 system (assignment system selected for SAMPERS) and the results of the forecasting system are stored by the system in a hyper cube. A special software (PowerPlay) is used for analysing and comparing results for different scenarios and for producing illustrations. Other components of the system compute external effects and additional evaluation indicators and conduct socio-economic cost-benefit analysis according to principles specified by the buyer group.

The user-friendly model interface (scenario formation, running mode, presentation and comparison of results, impact assessments) helps to manage the complex system. Running times for scenarios involving many of the sub-models and feedbacks between demand models and assignment models are still restrictively long. This is mainly due to the spatial and socio-economic detail. One remedy is to develop sketch-planning versions with less socio-economic detail. Another option would be to use the possibility of implementing parallel computations.

SAMPERS was used for the first time in 1999 in connection with the national strategic planning round. Analyses and impact assessments were conducted of measures and investment packages on the national level. Since then the system has been used in many contexts by SIKA and the transport agencies (e.g., the road and rail administrations) but also by other organisations and research groups.

In the folder on SAMPERS (and SAMGODS) issued by the Swedish Institute for Transport and Communications Analysis (SIKA) the following examples of applications were mentioned:

- SIKA´s forecasts of transport development until 2020 for the Swedish contribution to the UN climate convention 2001.
SIKA´s analysis of the profitability of passenger traffic by rail operators as a contribution to the governmental Railway Commission.

The analysis by national transport agencies of measures related to infrastructure programmes.

Analysis by consultants of the effects of congestion charging in the Stockholm region.

Two examples of output (drawn from the SAMPERS documentation) are provided in Figure 4.10 and 4.11. Figure 4.10 shows the number of trips by mode and distance class as presented by Cognos PowerPlay (bil = car, ICTÅG = train, X2000 = fast train, flyg = airplane, and buss = bus). Figure 4.11 shows accessibility in Scania as analysed by ESRI MapObjects. Accessibility can be analysed in a number of ways, e.g., as impedance measures (travel times to certain areas), closeness (number of destinations within a certain travel time) and model-based data, e.g., passenger distance travelled or logsum indicators.

Figure 4.10: Example of SAMPERS output (trip distributions)
4.3 A trip-based transport model from The Pilsen Region

Keywords: tactical, trip-based demand model, regional, passenger transport

Reference: Zdenek Melzer, SUDOP PRAHA a.s.

The Pilsen region transport model is an example of a classical four-step transport model based on trips. The model covers the most important modes of passenger transport. This model was developed by SUDOP PRAHA a.s. for the Transport Conception of the Pilsen Region. The project was financed by the Pilsen Region.

Objectives

The main goal of the Transport Conception of the Pilsen region project was to analyse a present stage in transport demand and supply, and to propose the set of measures and priorities that can have positive influence on transportation in the Pilsen region. The transport model of this region was developed for testing the possible transport measures. Following the European transport policy priorities, especially the possible modal shifts between private and public transport have been tested in relation to proposed measures. The results of this project can have a strong influence on the region land-use plan and on the general development of the Pilsen region.
Methodology

Area covered by the model
The Pilsen Region model covers the NUTS 3 Pilsen Region area and the surrounding area in Czech Republic and Bavaria. The model consists of 158 internal zones, 24 external zones in Czech Republic, and 12 external zones in Bavaria.

An interesting issue in setting up of this model was the cross-border transport. As we can see from Figure 4.12, the Pilsen region has a long border with Germany. This fact can raise some problems with gravitation principle in the model. Even in the united Europe, there are some economical and linguistic barriers, which need to be modelled realistically. In this case, the cross-border “impedance” was modelled by a time penalty on border crossings. The outputs were calibrated to annual census made on border crossings.

Figure 4.12: The Pilsen Region

The four steps of modelling
The traffic was calculated with detailed disaggregated supply-demand model in four steps:

1) Trip generation was based on defined “activity chains” for each defined socio-economic group. Activity chains describe probability of making some set of trips during an average day (e.g., Home – Work – Shopping – Home). Socio-economic groups consist of groups with similar transport behaviour (e.g., employed persons with car).

2) Trip distribution was based on a gravity model. Input data for the gravity model were attractions of zones and deterrence parameters disaggregated per activity and socio-economic group.

3) Mode choice: has been done by a multiple choice logit model (for car driver, car passenger, public transport, and walking) using indicators like: access/egress time, travel time, costs and other travel attributes (frequency and interchanges for PT) in the utility functions. Input data were logit parameters and indicator matrices.
4) Assignment was based on equilibrium assignment for the car traffic and frequency-based assignment for the public transport.

**Segmentation of model**

Activities:

- Home
- Job
- Shopping
- Private
- School
- University
- Recreation
- Long-distance

Because of very important highway connection (E50) to Western Europe in the modelled region, there was a need to establish a special “long-distance” activity and set up its probabilities and deterrence.

**Socio-economic groups:**

- Economically active with car
- Economically active without car
- Not economically active with car
- Not economically active without car
- Students < age 18
- Students > age 18

Students are divided into two groups because of different attractions (university, elementary + secondary school), and possibility of having a driving licence. Models have been calibrated to reflect conditions on an average weekday in the base year 2005. The frequency, mode, and destination models operate at the all-day level.

Prognosis of demand has been made for the years 2020 and 2030+. For the analysis of bottlenecks in the road network in these future cases, afternoon peak-hour matrices were made. Except of these cases, all calculations were made with all day matrices for public and private transport.
Data issues
The main data describing the transport infrastructure and zones borders are based on data from the Pilsen Region GIS and land-use plan. The socio-economic data were obtained from the Czech Statistical Office. The frequent problem with the transport behavioural data that are not statistically described on regional or national level was solved by a survey made directly for use in the demand part of the developed transport model.

Applications – use of the model

Assessment of scenarios
The model assessed five scenarios:

2005 present stage – this scenario was used for information about “accuracy” of model calibration and for analysis of present stage problems and bottlenecks in private and public transport.

2020 reference case - this scenario was based on assumption that in 2020 the network will be almost the same as the present. However, demographic and mobility changes will create a different transport demand.

2020 land-use plan – in this scenario the proposed stage of infrastructure was used as it is described in land-use plan of the Pilsen region. There has been made a prognosis of transport demand related to this stage of infrastructure.

2020 proposal – In this scenario, some proposals to road and rail network were tested, and some changes in public transport supply. The base for this proposals was the land-use plan of the Pilsen region.

2030 proposal – in this scenario the measures were tested that are not possible to apply until 2020.

The main proposed measures
Concerning the road network, the main proposed and tested measure was to identify the agglomerating and regional road ring in the Pilsen region (Figure 4.13). The main goal for this measure was to support not only radial but also tangential transport to Pilsen. This measure should help to revitalise the not so developed parts in Pilsen region. The network was mainly based on the existing infrastructure. The task for the transport model was to identify the capacity and speed bottlenecks in this network. Furthermore, the model tested proposed bypasses of towns and villages, possible changes of main roads to secondary roads and vice versa, possible changes in roads with very low traffic to cycle tracks, etc.

Figure 4.13: Overview of ring roads
Concerning the rail network, the main proposed and tested measure was to set up the new timetable for railways in Pilsen region. Due to the new timetable, some bus lines were changed to prevent duplicity in connections. Furthermore, the model identified railway lines that might suffer from low traffic flow in the future.

**Comparison of scenarios**

All scenarios were compared to see the “added value” of the transport conception proposals. The task was also done by the transport model of the region. As we can see on the first graph, the proposals help to solve the unsustainable situation in road capacity. The last two graphs present changes in transport passenger kilometres and passenger hours (for the graphical reasons in this case minutes). There is important growth in private transport in all scenarios. The LAND-USE and PROPOSAL scenarios help to shift some volumes from private to public transport.

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**Figure 4.14: Effects of scenarios on transport indicators**

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4.4 A tour-based model in Copenhagen, OTM

Keywords: tactical, tour-based demand model, regional

Reference: Goran Vuk, Danish Transport Research Institute

Objectives
The Ørestad Traffic Model (OTM) is the operative traffic model for the Greater Copenhagen Area (GCA) in Denmark. The GCA covers the city of Copenhagen and the surrounding area of the islands of Amager and Zealand in the eastern part of Denmark.

The model was originally built to predict the passenger demand for a metro that began its operation by the end of 2002. The model has a long history with a wide spectrum of applications. The first version was developed in 1994 with updates and revisions in 1996, 1998, 2000, and 2006. A main revision took place in the period 2005-2006 with updates of data and demand modelling and a switch to the new base year of 2004. This version of the model (OTM 5.0) is presented below.

Segmentations
The GCA is divided in the model into 835 zones, where 818 are intern zones. The OTM model system predicts demand for travel by six separated passenger purposes:

- home-based work (commuting),
- home-based education,
- home-based shopping,
- home-based leisure,
- non-home-based private trips, and
- business.

In addition, demand is predicted for two freight purposes:

- light trucks / vans, and
- heavy trucks / lorries.

The OTM 5 models consist of separate model components by purpose for:

- travel frequency (generation) at the all-day level.
- for passenger purposes, mode and destination choice, with five modes distinguished:
  - car driver,
  - car passenger,
  - public transport,
for freight purposes, destination choice.

The models have been calibrated to reflect conditions on an average weekday (i.e. Monday-Friday where summer months June, July and August are omitted) in 2004. The frequency and mode and destination models operate at the all-day level. Prior to assignment, the model predictions are split between the seven model time periods distinguished in the assignment models using fixed factors. The seven model time periods are: 21:00-05:00, 05:00-07:00, 07:00-08:00, 08:00-09:00, 09:00-15:00, 15:00-18:00 and 18:00-21:00.

For passenger trips, assignments are undertaken for each combination of six travel purposes, seven model time periods and five modelled modes. For freight trips, assignments are undertaken simultaneously with passenger cars over the seven model time periods. Once the assignments have been run for each model time period, all-day level-of-service is generated to feed back into the demand models.

### Frequency models

**Model structure**

The four home-based trip passenger purposes are tour based while the two other purposes are trip based. A tour is defined in the OTM to be a sequence of a simple trip from home to destination and a return simple trip from destination to home. In this way non-symmetric GA matrices are applied in the model, allowing us to distinguish between the home zone and non-home zone. By contrast, the modelling unit for non-home-based (NHB) travel is the trip, which is a single movement between two different locations.

The frequency model structure is presented in Figure 4.15. This structure is applied for both home-based travel, where the unit of travel is tours, and for non-home-based travel, where the unit of travel is trips. The model structure includes two sub-models:

- The first sub-model is a ‘zero/one plus’ model which predicts the probability that an individual will make any tours, i.e. the model predicts whether an individual participates in an activity.
- The second sub-model is a ‘stop/go’ model which predicts the numbers of tours that an individual will make given that they make at least one tour, i.e. the model predicts the level of activity participation.

The model structure is illustrated in the following figure.
The majority of individuals in the sample are observed to make zero or one tour for a given purpose and consequently the volume of multiple tours in the estimation samples is low. Therefore the same utility specification is used on the ‘1 tour’ and ‘2 tours’ utilities. The utility of the final ‘3+ tours’ alternative is set to zero. Across all model purposes, the utility specifications on the ‘1 tour’, ‘2 tour’, ‘3 tour’ etc. alternatives are set to be equal because the volume of data on multiple tours is low and so it is not possible to estimate separate parameters for each alternative.

Model estimation
To create the frequency models it is necessary to combine the following data files:

- for the home-based models, a tour file, with information about each tour observed in the survey data (i.e., in the rest of the note we refer to so called TU data as the survey data), together with a person-household identifier,
- for the non-home-based models, a trip file, with information about each trip observed in the TU survey data, together with a person-household identifier, and
- an interview file, with person and household information about each individual interviewed in the TU survey data, together with a corresponding person-household identifier.

It is emphasised that it is possible for an individual to make zero home-based tours for all purposes on the interview day, i.e. to remain at home all day. In this instance, they would appear in the interview file, but have no corresponding tour records in the tour file. Similarly, an individual may make zero non-home-based trips for all purposes on the survey day, so that they would appear in the interview file but have no corresponding records in the trip file. The processing had to account for these records in order to represent the frequency rates correctly.

Two sets of TU survey data have been used for the creation of the estimation samples:
2,613 interviews (persons) from 2003 – these are the sample of weekday observations from the GCA drawn from a survey of 13,148 interviews collected in 2003 across the whole of Denmark. Respondents aged from 15 to 85.

16,350 interviews (persons) from 2005 – all weekday surveys from the GCA but with respondents aged from 11 to 85.

It should be noted that the TU data only surveyed one person per household. The following sections summarise the steps that have been undertaken to create the HB and NHB frequency estimation samples:

- firstly, the processing of the tours/trips from the tour/trip files,
- secondly, the selection of the person samples for models – some models are only estimated for certain occupation types, and the different age bands surveyed in 2003 and 2005 need to be accounted for, and
- finally, the resulting estimation samples by purpose, summarising the observed tour frequency rates.

Three sets of variables are included in the frequency models: occupation type variables, car ownership variables, and personal income variables. Forecasts of these three sets of variables are provided on the zonal data file that is used to implement the models.

Simultaneous destination and mode choice models

Model structure
The models of mode and destination choice represent the choice of these two aspects of travel behaviour simultaneously. This is not because it is believed that the decisions on these aspects of the tour are in fact taken simultaneously. The requirement for simultaneous modelling and in particular for simultaneous model estimation arises from considerations of efficiency in the modelling.

The five mode alternatives are public transport (PT), car driver, car passenger, cycle and walk. Destination alternatives are only available if there is a non-zero attraction variable in the destination zone. The attraction variables that have been used vary according to journey. It should be noted that the zonal data used for model estimation only contains attraction variables for internal zones, and therefore all external zones are set to be unavailable in the models.

Model estimation
The initial home-work models were estimated from the 2003 and 2005 TU data alone (the RP data) with freely estimated cost and level-of-service parameters. In the initial models, it was possible to estimate a significant cost parameter using a linear-cost formulation in a model with a single PT in-vehicle time parameter. However when separate in-vehicle time parameters were estimated for each PT sub-mode (S-train, O-train, metro, city bus) the cost parameter was not significantly estimated. Furthermore, a model formulation with separate in-
vehicle time parameters by PT sub-mode and separate cost parameters by personal income band did not yield plausible results, with positive cost parameters estimated for higher personal income bands.

Obtaining plausible differences in value of time across different PT sub-modes and income groups was viewed as a key objective in this study. Given that home-work provides a large sample for model estimation it was clear that similar problems would be encountered in other model purposes where the volume of data available for estimation is lower. Therefore it was decided to constrain the values of time, for each income group, using results from models estimated from the Danish National Value of Travel Time Project (DATIV) SP data.

**Pivot-point procedure**
Traditionally, the OTM model applies a pivot-point procedure in the model forecasts. The procedure applies the ratio of model outputs for base and forecast situations as a growth factor to the base matrix, i.e., in a given cell the predicted number of trips \( P \) is given by

\[
P = B \cdot \frac{S_f}{S_b},
\]

where:
- \( B \) = observed base 2004 trips from the base matrices
- \( S_b \) = base year synthetic trips
- \( S_f \) = future year synthetic trips

The pivoting procedure makes best-estimate forecasts by predicting changes relative to a known base situation, defined by the base matrices (split by mode, purpose and time of day). The pivoting is carried out at matrix cell level. That is, for a specific origin, destination, mode and purpose, adjustments are made relative to the corresponding cell in a base matrix.

There is defined a number of rules for these cases where the above formula cannot be applied directly.

**Final processing**
When the demand sub-models are executed day matrices (for different travel purposes and modes) are produced. The final processing stage takes those matrices and processes them into matrices ready for assignment. Four steps are involved in this process:

- adding up – internal and external trips are combined and the demand model purposes are aggregated into the assignment model purposes,
- time of day factors – the all-day trip matrices by mode are split into the seven model time periods,
- pivoting – for a future year run, the predicted matrices are generated by combining base year and future year model predictions to predict changes relative to the observed base matrices (as explained above), and
- through and special trips – these are added in after pivoting but prior to assignment.
These four steps are illustrated in Figure 4.16.

Figure 4.16: Final Processing Overview

An important distinction is made in the final processing stage between internal, external and through trips. Internal trips have both origin and destination in the study area. External trips have either their origin or their destination in the study area. Through trips have both origin and destination outside the study area.

For internal trips, mode and destination choice has been modelled. For external trips, the numbers of trips by mode is specified for a given external zone and distributed over internal destinations to determine external to internal movements. The distribution over internal destinations is made using the same utility functions that are used to model mode and destination choice for internal trips. Internal to external movements are then taken as the transpose of external to internal movements. At the adding up stage, internal and external trips are combined.

The next stage is to convert predictions of demand at the all-day level into the seven time periods distinguished in the base matrices and used for assignment. These time of day factors have been applied to both internal and external trips.
It is considered to develop a time-of-day choice model, but until then, the distribution over time periods is achieved using fixed time of day (TOD) factors applied across all modelled modes (car driver, car passenger, public transport, cycle, walk). For the home-work, home-education, home-shopping and home-leisure purposes fixed time period proportions have been supplied for separately for outward and return tour legs, reflecting the significant differences in the time period distributions between outward and return tours legs.

The trip segments (business segment and the non-home private trips) also have their own TOD factors. These factors are representative of conditions across the whole model area and over the year, and are applied to all modelled modes.

After the pivoting procedure, the special/through trips need to be added up prior to assignment. Special and through trips are defined by OD pair, assignment purpose, mode and time of day by input files read in by the model system. In some cases, it may be desirable to replace the model forecasts for a particular OD pair with other demand forecasts and in this instance a ‘special trips’ file would be defined. As special and through trips are fully specified by separate input files, they are added in after the pivoting process has taken place.

Applications
OTM is a state-of-practice model designed for general use in tactical planning contexts on the regional level:

- Demand effects of new infrastructure or new services (projects, programmes).
- Demand effects of, e.g., income, car ownership, population, and employment changes.
- Assessment of pricing and regulation policies: public transport fares, road pricing, parking costs, road tolls, fuel costs, etc.

OTM has been applied in many projects: public transport projects (metro, rail, and bus service changes), road projects (motorways, harbour tunnel, etc.), policy issues (road pricing, parking cost, fare, etc.), and land use changes (developments of new city areas, shopping centres, and industries).

The first application of the new version of OTM is to forecast the market share of a new metro ring line in the City Centre of Copenhagen, which is expected to open in 2018. Jovicic (2003) and Vuk (2006) include a description of the OTM version (OTM 4.0) prior to the current version. At the moment of writing, documentation of OTM 5.0 in English is only available as working notes (estimation of passenger demand models and system descriptions) and conference papers, e.g., Nielsen (2006).
4.5 The Boston activity-based model – a prototype

Keywords: activity-based, demand model, tour-based

Reference: Dr. John Bowman, Bowman Research and Consulting

Introduction
The description contained here is based on Bowman and Ben-Akiva (2001), where a prototype version of Bowman’s original model from 1995 is described. The model is a prototype of the day activity schedule model system, developed using data from the Boston metropolitan area, including a 24 h household travel diary survey collected in 1991, as well as zonal and time-of-day-specific transportation system attributes from the same time period. Survey respondents reported activities requiring travel, and details of the associated travel.

The following section presents a description of the model specification and associated data preparation issues. It begins with an overview, then proceeding to describe the pattern and originally the tours models. In the subsequent section, we present part of the results of model parameter estimation. The final section discusses the prototype, focusing on the implications of its limitations and the prospects for an operational implementation.

Prototype specification
The probability of a particular activity schedule can be expressed in an activity-based model as the product of the marginal pattern probability and a conditional tours probability:

\[ p(\text{schedule}) = p(\text{pattern})p(\text{tours/pattern}) \] (4.1)

To implement the basic structure of (4.1), the prototype groups the elemental decisions of the activity schedule into five major tiers, including:

1. activity pattern, which is the marginal model of (4.1), plus four tiers that together constitute the conditional tours model system:
   a. primary tour time of day,
   b. primary destination and mode,
   c. secondary tour time of day,
   d. secondary tour destination and mode, as shown in Figure 4.17.

The activity pattern is a nested logit model as depicted in Figure 4.18. It represents the choice between a pattern with travel and one without. The upper level is a binary choice between staying at home all day and a pattern with travel. Given the choice of a pattern with travel, it also includes the conditional choice among 54 patterns with travel.

The utility function of each pattern includes the expected maximum utility variable from the lower level tours model alternatives, providing the link that makes the entire activity schedule a sequentially estimated nested logit model system. Each activity pattern with travel is defined by a primary activity, a primary tour type and the number and purpose of secondary tours.

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3 Information on the development of the latest version can be found on jbowman.net.
The primary activity is defined as the most important activity of the day. If it occurs on a tour, this tour is designated the primary tour and all other tours are designated as secondary.

Figure 4.17: Lower tier models are conditioned by decisions in higher tiers

Figure 4.18: Nested logit model of the choice of activity pattern

With this definition it is necessary to identify in the estimation data set the most important activity of the day, this information is not available in the Boston data. Lacking this information, a deterministic rule is used based on the research of Hague Consulting Group (Antonisse et al., 1986) who investigated the ability of various deterministic rules and a stochastic model to match priorities reported by survey respondents. They found a simple deterministic rule worked best, but it matched the reported priority in only 76% of the cases, and did not report the success rate for non-work patterns, which we suspect were even lower. If, as we propose, the model design should be based on activity priority, it would be advisable to collect activity priorities directly in activity/travel surveys.

In the selected rule, all the activities within a tour are ranked by priority, with work being the highest priority, followed in order by work related, school, and all other purposes. Ties are
broken by assigning higher priority to activities of longer duration. Within an individual’s activity pattern the tours are assigned relative priorities by giving highest priority to the tour containing the highest priority activity, and so on until all tours are assigned a priority. Each dimension of the activity pattern is discussed below. The primary activity is classified as home, work, school, or other. This classification is somewhat arbitrary and quite limited. A more customary classification distinguishing subsistence (work or school), maintenance (household or personal business activities) and leisure (activities engaged in for pleasure, recreation or refreshment) may be more appropriate. Tour type is defined by the number, purpose and sequence of activity stops on the tour. The prototype partitions the observed work tour types into five categories. The three predominant categories are

a) the tour from home to work and back again with no additional stops (hwh),

b) the tour with at least 1 additional stop for another activity (hwh+), and

c) the tour with a work-based subtour for another activity as well as any number (including zero) of additional stops for other activities (hw+ wh).

Two additional work tour categories involve mid-tour returns home, one with no additional activity stops (hwhwh) and another with one or more additional stops (hwhwh+). School and other tours received a simpler categorisation involving only the analogies of the first two work tour types. We subsequently sometimes refer to type (a) tours as simple and all other tour types as complex.

The prototype classification lacks important sequence and purpose information. For example, it is unable to distinguish a pattern with a maintenance stop on the way to work from one with a leisure stop after work, two patterns that would have significantly different utilities. A better method would distinguish tour types by the presence or absence of purpose-specific secondary stops at three temporal locations on the tour - before the primary stop, after the primary stop and, for work tours, a work-based sub-tour (see Bowman, 1998 for details). This would enable the model specification to significantly improve its explanation of pattern choice, and allow the use of more accurate availability constraints in secondary stop models.

The prototype’s classification of the activity pattern decision by number and purpose of secondary tours distinguishes 2 purposes and 3 frequencies. The first purpose category - constrained - includes purposes that usually involve tight schedule constraints, including work, work related, school, and banking/personal business; the second category - unconstrained - includes all other purposes. The 3 frequencies are 0, 1 and 2 or more secondary tours. The feasible combinations of purpose and number yield a set of six alternatives, including

a) 0 secondary tours,

b) 1 secondary tour with schedule constrained purpose,

c) 1 secondary tour with schedule unconstrained purpose,

d) 2 or more secondary tours with schedule constrained purposes,

e) 2 or more secondary tours with schedule constrained and unconstrained purposes, and

f) 2 or more secondary tours with schedule unconstrained purposes.
Table 4.1: Activity pattern alternatives and their relative frequency

<table>
<thead>
<tr>
<th>Primary activity</th>
<th>Primary tour type</th>
<th>Number and purpose of secondary tours</th>
<th>Percentages</th>
<th>Workers</th>
<th>Non-workers</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>At home</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
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<td>13.76</td>
<td>13.27</td>
<td>9.48</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 constrained</td>
<td>3.86</td>
<td>2.77</td>
<td>2.77</td>
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| Total            |                  |                                       | 100.00      | 100.00  | 100.00      |       |

An improved representation would use the same purpose categories for primary and secondary tours - subsistence, maintenance, and discretionary - making it easier to capture purpose-specific inter-tour trade-offs.
The categorisation of the activity pattern by purpose, primary tour type and number and purpose of secondary tours, as described above, yields a choice set of 55 alternatives in the Boston prototype, including the home pattern, 30 work tour patterns, 12 school tour patterns, and 12 other tour patterns. Figure 4.18 describes the choice alternatives for the 3 dimensions of the activity pattern, and Table 4.1 lists all 55 alternatives and their relative frequency in the sample.

The collection in the diary survey of information about activities conducted at home would enable a more detailed categorisation of patterns with at-home activities, and could lead to a restructuring of the model’s hierarchy. For example, the model might distinguish the primary activity of the day not only by three purposes, but also by whether it is conducted at home or on a tour, allowing for the possibility of secondary tours in all six cases.

As defined in the Boston prototype, any activity schedule with travel always has a primary tour, and may have zero, one or more secondary tours. The conditional tours probability of (4.1) consists of the joint probability of all modelled dimensions of all the tours in the schedule.

The secondary tours are modelled conditional on the primary tour outcome, so the tours probability is expressed as the product of the primary tour probability and the conditional probability of the secondary tour outcomes, given the primary tour

\[ p(\text{tours/pattern}) = p(\text{secondary tour/pattern}) p(\text{secondary tours/primary tour}) \]  

(4.2)

Secondary tours are considered to be mutually independent and the conditional secondary tours probability is expressed as

\[ p(\text{secondary tours/primary tour}) = \prod_{t=1}^{T} p(\text{secondary tour}_t/\text{primary tour}) \]  

(4.3)

where \( p(\text{secondary tour}_t/\text{primary tour}) \) is the conditional probability of the dimensions of secondary tour \( t \) given the primary tour, \( t = 1, \ldots, T \) and \( T \) is the number of secondary tours in the schedule. All secondary tour probabilities are calculated from the same secondary tour model. This approach ignores time constraints and correlation across secondary tours, but simplifies the model structure, which would otherwise involve repeated conditional tour nesting via a secondary tour, tertiary tour, etc.

Substituting (4.2) and (4.3) into (4.1) we obtain the expression of the activity schedule probability as specified in the Boston prototype:

\[ p(\text{schedule}) = p(\text{pattern}) p(\text{primary tour/pattern}) \prod_{t=1}^{T} p(\text{secondary tour}_t/\text{primary tour}) \]  

(4.4)
For the primary tour and each of the secondary tours, the time of day, primary destination and mode are modelled, with the choice of mode and destination conditioned by the time of day choice

\[ p(\text{tour}) = p(\text{timing}) p(\text{mode, destination}|\text{timing}) \quad (4.5) \]

A weakness of the Boston prototype is the lack of explicit models of secondary tour stops, an important feature for accurately capturing trip chaining behaviour and inter-tour trade-offs. To handle this (4.5) might be enhanced by modelling secondary stops conditional on the primary stop choice, representing the tour probability as

\[ p(\text{tour}) = p(\text{timing}) p(\text{primary tour}|\text{pattern}) \ p(\text{secondary stops}|\text{timing, mode, destination}) \quad (4.6) \]

**Tour time of day models**

Two similar MNL models of the choice of tour time of day are estimated, one each for secondary and primary tours. Each of the 16 alternatives is comprised of 1 of 4 time periods for departure from home to the primary destination and 1 of 4 time periods for departure from the primary destination returning home. These 4 time periods include AM peak (6:30-9:29 AM), midday (9:30 AM-3:59 PM), PM peak (4:00-6:59 PM), and other (7:00 PM-6:29 AM). All time periods are considered available to all persons for primary tours. For secondary tours, times that overlap with the chosen primary tour time are removed from the choice set.

**Tour destination and mode choice models.**

The destination and mode choice model involves the choice of a mode for the tour instead of the usual choice of mode for a trip. The Boston survey respondents did not report their travel mode on a tour basis, but instead reported every mode used, in sequence, sometimes reporting several modes for a single trip, with different sets of modes used for different trips in the same tour. Thus, the modeling of a tour mode choice required a decision rule for translating a large set of potentially complex sequences of reported modes into a smaller choice set of tour mode alternatives. The rule selected was able to automatically assign over 98% of the sample to one of six modes, including auto drive alone, auto shared ride, transit with auto access, transit with walk access, walk and bicycle. Additional rules were used to judge which of the 6 mode alternatives were available to each person in the estimation data set. For more details see Bowman (1995).

The definition of mode alternatives could be enhanced within the proposed model system framework to include more sophisticated mixes of intermodal travel, as is sometimes done in mode choice models. It would also be possible to define some alternatives in terms of two modes, namely the modes used for the outgoing and return trips, respectively. If secondary tour stops were explicitly modelled, mode choice could be modelled if it was likely to occur, such as for work-based sub-tours.

An important difference between the primary and secondary tour model specifications is the inclusion in the primary tour model of the expected maximum utility variable, computed from the secondary tour model. This link turns the models into an informal nested logit system. The calculation of the expected maximum utility requires a special application of the theory of the
nested logit model to capture the expected maximum utility from a multiple number of secondary tours. The resulting expected maximum utility of all secondary tours is equal to the sum of the expected maximum utility of each of the tours. Since the expected maximum utility of a single tour is equal to the logarithm of the sum of the exponentiated systematic utilities of all available tour alternatives (logsum), the expected maximum utility among multiple tours is simply the sum of the logsums across all secondary tours in the pattern.

Model estimation results

Model parameters were estimated simultaneously within each tier and sequentially across tiers. Three factors prevented the simultaneous estimation of the model’s parameters across two or more tiers. These include

(a) the independent nesting of multiple conditional secondary tours,
(b) the use of alternative sampling for destination choice, described later, and
(c) our desire to work within the capacity limits of commercially available nested logit estimation software (all models were estimated with ALOGIT, by Hague Consulting Group).

The sequential estimation procedure yields consistent parameter estimates that are different than simultaneously estimated parameters. It also yields inconsistent estimates of the standard errors of the parameter estimates; they are usually underestimated, especially for the parameters of the expected utility variables. The reported standard errors presented here have not been corrected. Estimation results are presented for the destination and mode choice models. For the results on time of day and the activity pattern, the reader is referred to Bowman and Ben-Akiva (2001).

The tour destination and mode choice models are estimated as multinomial logit (MNL) models with alternative sampling. A sample of up to 48 alternatives is constructed for each tour in the data set, using stratified importance sampling (Ben-Akiva and Lerman, 1985, p. 266). The sample includes 8 of 786 possible geographic zones, with up to 6 modes available for each destination. Details of the sampling procedure are provided in Bowman (1995).

Estimation of the destination and mode choice model requires the definition of transportation system level of service variables and preparation of such data for all mode alternatives, by the four time-of-day categories used in the time of day choice models. Interzonal roadway distance is used as the transportation system level of service measure for walk and bicycle modes, since the data set provides no good level-of-service attributes such as travel times, bikeway availability or sidewalk connectivity. Costs and travel times are defined in traditional ways, although the models require values of these attributes by time of day.

Table 4.2 shows the complete estimation results of the destination and mode choice models for primary and secondary tours. The specification reflects a substantial amount of testing and respecification, and is adequate for demonstrating the proposed model system design, but retains some important deficiencies that would need to be corrected in an operational implementation. In particular, although the coefficient signs for the level of service variables are correct, they imply unreasonable values of time in some cases, indicating the need to check further for data problems and improve the model specification. For instance, for a household with annual income of $54,000, the value of auto in-vehicle time on secondary
tours is too high at $114 per hour, and for transit, the value of out-of-vehicle time is lower than that of in-vehicle time.

The following discussion highlights differences in behaviour between primary and secondary tours, a feature of the model system that differentiates it from typical trip and tour-based models. The presence of cost (coefficient 6 in Table 4.2) in the primary work tour model, accompanied by cost/income (coefficient 10) that is smaller for the work tour, indicates that low income does not increase cost sensitivity as much for primary work tours as it does for non-work and secondary tours. Coefficient 7 in both work and non-work models indicates that the presence of any or all of the employer incentives of mileage allowance, subsidised parking or company car tends to offset the disutility of the cost of driving alone. Coefficients 8 and 9 yield similar, but even stronger effects on the disutility of transit costs in the presence of employer subsidised transit passes, but this effect occurs only for work tours. The socioeconomic variables of auto availability and income have substantially different mode choice effects for primary tours than for secondary tours.

Since the secondary tour destination and mode choice model is conditioned by the choice of destination and mode for the primary tour, the actual choices of mode and destination in the primary tour are used to explain choices in the secondary tour. Coefficients 25-27 indicate a tendency for people who choose drive alone, shared ride or bicycle in their primary tour to choose the same mode again for their secondary tours, with the effect being dramatically strong for the bicycle mode: the effect is insignificant for the other modes. Coefficient 28 indicates a similar effect in destination choice for work tours, with persons tending to choose the same destination zone for secondary work tours as they choose for their primary (work) tour. Coefficients 30 and 31 capture trip-chaining tendencies.
Table 4.2: Tour destination and mode choice models

Finally, coefficient 34 is the logsum coefficient associated with the expected maximum utility of secondary tours. It is in the acceptable range for nested logit models, and reveals a strong in-fluence of secondary tour utility on the choice of alternatives in the primary tour. Activity patterns with more secondary tour travel, due either to more or longer tours, generally have smaller values (less positive or more negative) of the logsum variable. Thus, the positive sign
of this coefficient means that primary tour alternatives that are linked in an activity pattern with a substantial amount of secondary tour travel will have lower utility than those with little or no secondary tour travel, all other things being equal.

**Evaluation of the prototype**

The purpose of the prototype was to demonstrate the concept of the activity schedule model system, test important features, and gain an initial evaluation of the method’s potential for further research and operational implementation. A number of simplifications were introduced that may limit the prototype’s prediction capabilities. Here these limitations are summarised, giving special attention to impact on model performance and the prospects for remedies in subsequent development.

**Time-of-day models**

The weakest components of the model system are the time of day models because level-of-service variables are not included. However, these models interact with other policy sensitive dimensions of the activity schedule via the conditionality hierarchy. As a result, while timing choices are not influenced by transportation system level of service via travel accessibility, they are affected indirectly by accessibility’s influence on the activity pattern, and the conditioning of time of day on the pattern choice. The time-of-day dimension is defined very coarsely so that, even if the model specification was enhanced to include accessibility’s direct influence, the responsiveness to level of service would be crude. Effectively incorporating time-of-day choice requires finer resolution of the time-of-day dimension, accessibility linkages with the other dimensions of the model system, and better explanation of time of day choice. The lack of a strong time-of-day component does not, however, undermine the ability to capture inter-tour trade-offs in the activity schedule, an important improvement over tour-based models.

**Secondary stops on tours**

This dimension is missing entirely from the prototype, and reduces the ability of the model to accurately represent inter-tour trade-offs involving trip chaining, one of the important features of the model design. Without secondary stops, the model relies too heavily on matrix adjustments for stops during not modelled model system operation. For example, it cannot capture correlation among destinations of stops on a tour. This simplification is not inherent to the proposed design, and the secondary stops can be included in an enhanced implementation, as they are included in existing tour-based model systems.

**Activity pattern model**

This model explains very little of the observed variability in pattern choice, with measurable but small responsiveness to transportation policy via the accessibility variable. The proposed system structure provides an excellent context for further research and development into the factors influencing pattern choice, such as demographic outcomes and lifestyle decisions. Prospects of improving the measurement of activity and travel accessibility’s influence are also good, through the enhancement of the tours portion of the model structure.
Nesting hierarchy
Although the hierarchical relation of activity pattern to tours is statistically established in the prototype, and provides a clear advantage over existing operational econometric models, several important structural issues were not fully analysed, including

(a) the relation of the time of day decision to the mode and destination choice, 
(b) correlations within tiers, 
(c) cross-correlations not accommodated by nested logit.

Further research and development may lead to important structural model enhancements.

Values of time
Unrealistic values of time indicate model specification errors and/or data deficiency that were not resolved in the prototype. As specified the model would produce counterintuitive predictions in some cases. Achieving realistic values is a reasonable pre-requisite for final acceptance of the model, calling for more specification testing with new data.

Mutually independent secondary tours
This simplifying assumption unrealistically violates temporal constraints, spatial correlation, and conditionality arising from priority-based behaviour. The simplification is not inherent to the proposed design. Some relaxation of the assumption may be possible, such as introduction of a tertiary tour, but a complete representation of relationships among secondary tours may produce a model of unmanageable size.

Coarse classification within choice dimensions. Many of the prototype’s classifications of alternatives are arbitrary and/or very coarse. These include activity purposes (work, school, other), tour type (did not identify purpose or tour placement of secondary stops), secondary tour purposes (inconsistent with primary tour purposes), mode (few mixed mode alternatives), destination (traditional zonal aggregation) and time of day (four time periods). Redefining inferior or inconsistent classifications poses no problem, but refining resolution, especially desirable for destination and time of day choices, presents many challenges because it can substantially increase model size and the need for detailed spatial and time-specific location and travel characteristics.

The standard method of handling large choice sets, alternative sampling, is used in the prototype for destination choices, and might be employed to handle extremely fine resolution of destination and time of day dimensions. Sampling of alternatives and simplification from a pure nested logit structure - mentioned in the previous paragraph - preclude the use of existing simultaneous estimation procedures. Sequential procedures are required that yield less efficient estimates and make testing cumbersome, not only because the usual standard error estimates are inconsistent, but also because they increase the effort required to test alternative structures. If these complications can be overcome, then the use of fine resolution, especially in the destination and time of day dimensions, may significantly improve the proposed model system.
At-home activities
The prototype does nothing with at-home activities because such information was not collected in the Boston survey. This limits the ability of the prototype to fully capture the activity basis of travel demand, but does not prevent the capture of basic at-home versus on-tour trade-offs and inter-tour trade-offs. Data availability is an important concern, and further research and development may sharpen understanding of data requirements enabling more efficient collection of the most important at-home information.

4.6 TRANSURS, Multimodal Transport and Impact Model
Keywords: tactical, tour-based demand model, regional, congestion pricing

Reference: Transman

TRANSURS – acronym stands for Transport in Urban and Regional Systems – is an in-house transport model developed by TRANSMAN Consulting covering demand modelling and impact calculation. Instead of the classical four-step theory for passenger transport it is based on daily trip chain modelling, so the home-based and non-home based trips are dependent on the initial mode choice. The model was developed for Budapest and its surrounding based on the household surveys from 1992-94.

Objectives
Transport systems should be understood as a space-time-cost system. The interaction among available modes, the capability of the different user groups and the variable attributes of supply are the basic characteristics of the passenger transport system. In most of the cases the policy and measure assessment requires such models that are able estimate the possible effects in demand modelling as whole.

A direct driver of the model development was the investigation of the impacts, which could be caused by theoretical road charging measures regarding the energy savings in Budapest in EUROPRICE (Energy efficiency of Urban ROad PRicing Investigation in Capitals of Europe) RTD 4th FP project. Its objectives were as follows:

1. To assess the fuel saving potential of urban road pricing schemes in several European capital cities.
2. To extend and refine the findings of previous SAVE projects and other relevant urban road pricing initiatives by EU member states and the European Commission.
3. To test road use charging equipment in several urban areas, in terms of user response (before and after a field trial), public acceptability, interoperability, and energy efficiency implications.
4. To relate energy efficiency to integrated urban transport pricing and associated demand management measures.
5. To disseminate the findings to other capital cities, particularly in Central and Eastern Europe.
Within the framework of the EUROPRICE EU-project, finished in 1999, various charging experiments and modelling calculations were executed in London, Dublin, Athens and Budapest.

In the case of Budapest by applying the TRANSURS model system the analysis of various charging (access fee) scenarios have been carried out by.

**Methodology**

The TRANSURS model package contains the determination and distribution of the passenger and freight flows, the calculation of the road and public transport network loads and the quantification and evaluation of the different impacts (time, operation cost, air pollution, noise, etc.). The passenger traffic was calculated with detailed supply-demand models, while the freight transport used simpler grow-factor models.

The passenger demand models describe trip chains of population groups by activity, car availability, and public transport pass ownership. The main features of the passenger model are:

**Trip generation:** the mobility (trip rates) of a given group is influenced by the “potentials” of the origin zones, what is measured by the attraction of the destination zones considering the generalised costs of the interzonal relations.

**Trip distribution:** the destination choice was modelled in two steps: first a logit choice model was used for determining the greater area relations from the given origin zone and secondly the flows were distributed inside each area with a simpler gravity weight model.

**Mode choice:** has been done by a multiple choice logit model (for car driver, car passenger, public transport, bike, walk) using travel time, costs, and other travel attributes (frequency and interchanges for PT and parking space availability and fees for cars) in the utility functions

**Assignment:** equilibrium assignment for car and truck (bus) traffic; frequency- and schedule-based assignment for public transport

**Value of Time:** This was derived from a revealed logit analysis of mode choice

**Traffic volume dependent indicators:**

- time-fuel consumption
- operation costs
- air pollution

The calculation method is based on the link traffic loads coming from the assignment. It calculates the consumption for links and nodes. The determination of the used fuel considers the traffic conditions and is done for cars, trucks, and buses.

**Relation based indicators:**
For the scenario evaluations, the model uses a MCA method to assess the socio-economic potential. The approach is based on the accessibility calculations and structural attributes of zones (e.g., net tax revenue, age distribution, skill level of workers).

The model calculations are carried out in one single step – unlike the former separation of trip generation, distribution, and splitting – “standing” in one of the zones and following all chain types of the traveller groups one after the other, recording all intermediate stops and returning to the origin (meanwhile carrying out the mode choice according to the mode availability and utility values of the examined traveller group). The daily and peak hour modal traffic flows of the entire city can be gained by working through all zones, traveller groups, and chain types.

Another important feature of these models is that connections and results are more dependent on the supply characteristics of the transport system (time, cost, service characteristics). This actually makes them more sensitive.

Data issues
The transport models were based on household surveys from 1992-94. The year of calibration was 1995. Besides the road network, the network model contained the entire public transport network.

Applications
The primary use of TRANURS was the calculation of the road charging (access fee) effects but later a number of projects utilised its capabilities and results, e.g., passenger behaviour analyses, public transport network optimisation, investigations of the M0 ring-motorway around Budapest and the investigations in connection with the establishment of the Budapest Transport Association.

Detailed description of the EUROPRICE case study application

Transport network structure
Budapest, the 2 million capital city of Hungary is located on both sides of the Danube River. On the right hand side there is the hilly Buda, with the castle district and on the left hand side the plane Pest lays with a concentration of work places and institutions in the city. The road network on the Pest side shows a ring-radial shape, where besides the Big Ring, The Hungária Ring is the main connecting element and where the back bone of the dense public transport network is outlined by the three metro lines.

In the road network of Buda, the western part of the Big Ring is the only connecting element for the different roads shaped by the moved topography and with more conventional public transport. Inside the Big Ring there are five out of the seven Danube bridges which are inside the boundaries of Budapest (one more bridge of the M0 motorway is south from the town). This results in a high concentration of road traffic in the inner part of the city. On 2.1% of the area of Budapest concentrates 7.4% of the traffic, 12.0% of time consumption, 9.7% of fuel consumption and 6.4% of air pollution.
Traffic concentration in the city

The inhabitants of Budapest make around 5 million trips a day of which the motorised trips are less than 4 million. The modal split is around 60:40. It shifts year by year to the disadvantage of public transport, because of the permanently increasing motorisation. The motorisation rate is around 320 cars/1000 inhabitants. From the daily 300-350 thousand people who are involved in destination and transit traffic around 60% come with car. This together with the substantial truck traffic cause daily congestions on the radial and outer ring roads. On the road network in the inner part of the town concentrated on narrow space trucks over 3.5 tonnes are banned and substantial public transport operates. Into the inner part of the city, the share of car traffic is lower than the average, but 68% of the car users going from home to work return from the work place directly home again (see Figure 4.19).

In spite of the fact that among the trips to the city the ratio of the car traffic is lower than at the Danube crossing passenger transport the tendency is worsening if we consider the increasing motorisation. Main parts of the through traffic also pass the inner city and cross one of the five bridges inside the Big Ring causing congestions in most part of the day, hindering also the public transport on the roads.

Figure 4.19: Car trips to the city by trip origin, purpose and leaving trip destination

Transport policy implications

The transport policy of Budapest has changed a lot in the last decades. The environmental issues have become more important, so in the latest Transport System Development Plan the following main goals have been formulated:
• Reducing demand for transport by improved land use management;
• Improving traffic organisation and management;
• Mitigating the environmental impacts of transport activity;
• Minimising costs and improving the efficiency of the transport system.

With the increasing motorisation, the congestion and the air pollution has become critical especially in the inner part of the city. At the same time within the transport development, the public transport (BKV) is decreasing (see Figure 4.20), because of the disappearance of most of the “mass working places” and the declining service provision caused by of financial problems.

![Figure 4.20: Development tendencies of car traffic and public transport in Budapest](image_url)

The investigated access fees should serve in first line as a measure to influence the behaviour of car drivers, the destination, mode, and route choice to reduce congestion, the harmful environmental burdens and other external costs. Only secondly, they should serve to gather revenues. The model calculations for Budapest in the frame of EUROPRICE can be seen as theoretical exercises only, without any political relations, because at the time road pricing or access fees were early ideas in Budapest.

**Modelling work**

The TRANSURS model system for destination choice and mode choice applies logit models. It became obvious that simultaneous models were necessary, because models with trip-end or trip interchange mode choice do not deliver realistic results. The reason for this is that the
“holistic” all-mode relational deterrence functions (generalised costs) are not sufficient to calculate realistic zonal and modal shifts in passenger transport, because not all modes are influenced by the access fees. The scenarios can be characterised as follows:

a) **Reference scenario**: This represents the "current" (1995) situation. All other cases are evaluated by comparing them to this case.

b) **Scenario 1** - Danube Crossing Tolling: The bridges inside the Big Ring would be tolled, Margit and Petőfi bridges, as part of the ring, with 1 toll unit and the three other inner bridges with 2 units.

c) **Scenario 2** - Inner City Tolling: All entrance road sections in the Inner City Area inside the Big Ring would be tolled with 2 toll units as well as the two bridges on the Ring. The three inner bridges would be tolled with 1 unit only.

d) **Scenario 3** - Pest Side Tolling: To protect the Pest Side of the city more the tolling considers roads inside the outer Hungária ring, too. In this case, the entrance roads and the 5 Danube bridges serve as toll screen lines. The entrance roads of the outer Hungária ring would be tolled with 1 unit. The access fee for the Inner City Area would be an additional 1 toll unit as well as the two Big Ring bridges. The inner bridges would be tolled with two units.

e) **Scenario 4** - Theoretical case: Same as Scenario 1 but in this case we examined also the effects on mobility of road pricing. Because of the distortions in the relationship between the zone potential and specific trip rate derived from the surveys this effect type had to be eliminated from our later evaluations.

The assumed cordon unit fee is relatively high, it equals two public transport tickets (price in 1995: HUF 25/ticket), in case of the inner Danube bridges an additional fee of two units has been assumed traffic for a crossing comparison of the fee level: at this time the price for 1 litre of petrol was around 95 HUF). The introduction of access fees brought change in the generalised costs what influenced trip rates, the destination distribution and the modal shares of the participants of transport and further the routes of the car drivers (the trucks are prohibited from the inner part of the city).

The results of the logit-based traffic flow calculations based on the generalised transport costs (time, fuel, service conditions + access fee) for destination and mode choice in respect of the around 75 passengers and trip purpose groups provided the input for an equilibrium traffic assignment. The results are shown on the load map and load difference map for the most favourite Scenario 2 (Figure 4.21), where the decrease of the traffic in the city and the increase in the less sensitive outer areas can be observed.

To the traffic models different impact modules are connected that allow the calculation of time, energy (fuel consumption), air pollutions, noise levels, and accidents.
In the EUROPRICE project the main aspect was the energy saving, which was extended to savings in time consumption and air pollution (represented by NOx for local pollution).

**Main findings**
The modelled quantities and indicators have been grouped by origin:

- inner city (inside the Big Ring)
- interim area (between the Big Ring and Hungária Ring on the Pest side)
- other areas (outside of the inner and interim areas on both parts of the city).

The main results can be summarised as follows (see Figure 4.22):

- The departing and destining traffic in the direction to the inner areas would decrease overall by approximately 4% all (in the calculations the differentiation between the inhabitants and other travellers was not possible.).
- The proportion of the transport modes would change as follows: private cars -40%, public transport +8%, bicycles +3%, pedestrians +2%.
- Compared to the base scenario the different modes in the inner districts of Budapest as well as in the whole city would change as follows: destination traffic of private cars (-42/-4%) traffic performance (-48/0%), time spent in the traffic (-65/+1%), fuel used (-54/-1%) emitted nitrogen-oxide (NOx) (-31/+3%) – decrease (-), increase (+).
Figure 4.22: Modal shifts because of road pricing in Budapest (2nd Scenario)

- The traffic loads of the network in the inner areas and on the bridges would considerably decrease; part of the ‘edged off’ excess traffic would appear on Lágymányosi bridge and Árpád bridge, where this traffic would still cause less additional external costs than in the inner districts.

- The annual fare box revenue – which is not an unimportant aspect – would be HUF 7 billion/year (in case of 1995 prices).

In the course of the theoretical modelling, we did not deal with the technology of fee collection, investment demands and operational costs. Consideration of this was not possible due to the given framework and conditions.

The elaborated modelling task showed that TRANSURS model could trace the impact of such measures with an adequate accuracy. The results proved that such pricing measures generate advantageous traffic and environment impacts locally but one should take care of global effects as well. The road pricing measure generates substantial additional fare box revenue; this would be HUF 7 billion/year (1995 prices) in Scenario 2.
5 Economic modelling best practice

5.1 CGEurope, TRANS-TOOLS

Keywords: Computable general equilibrium, European model, regional distribution, part of model complex

Reference: Prof. Johannes Broecker, Christian Albrechts University

CGEurope in TRANS-TOOLS is a European computable general equilibrium (CGE) model that is modified for the specific use within the model complex. The basic structure of the model remained the same in the two model versions. The version reported here is the version applied in TRANS-TOOLS. An important difference between the two model approaches is that there is only one sector in the TRANS-TOOLS version due to a concern that the detailed model would prevent users from having full flexibility of using the model (e.g., in determining the tested scenarios). The description here is based on TNO (2006).

Input/data needs
Table 5.1 reports the list of data required by the regional economic model. The data are subdivided into input and calibration data. Calibration data are used to determine all parameters of the model equations and accommodate the model to the real world data. Input data are used for model simulation runs. The data to be used in CGEurope can roughly be subdivided into five categories, namely (1) national accounts data, (2) regional data, (3) trade data, (4) transportation costs data, and (5) model parameters.

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<td>Value of output of each industry in each region</td>
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</table>

Table 5.1: Data requirement for the economic model

**National Accounts**

For the sectoral disaggregation of CGEurope, information is needed on input-output coefficients as well as on trade flows by commodity. The complete disaggregation of industries in the economy according to the full NACE system of sectors is not reasonable not only for data availability reasons, but also for modelling reasons. The main problem of the modelling part is that the freight model divides industrial production into commodities, whereas the CGEurope divides the production into sectors. The choice of the sectoral disaggregation therefore has to take account of a correspondence between commodities and sectors that should go as far as possible. Therefore, the model divides the economy into five sectors: A to E, defined in Table 5.2.

This sectoral disaggregation allows us to establish a correspondence between GTAP and NSTR commodity classifications, first being the base for input-output information, and second for trade flows and cost information. In this way, each commodity type is used as an input by all sectors, but is produced by only one. GTAP also provides the total production and final demand figures for all countries in the model.
Industry in the model | NSTR code | GTAP sectors included |
--- | --- | --- |
A | 0 | PDR, WHT, GRO, V_F, C_B, PFB, OCR (part), CTL, OAP (part), RMK, WOL, FRs, TEX |
A | 1 | OSD, OCR (part), OAP (part), FSH, CMT, OMT, VOL, MIL, PCR, SGR, OFD, B_T |
D | 2 | COA, P_C (part) |
B | 3 | OIL |
D | 4 | OMN (part), I_S, NFM |
C | 5 | FMP |
D | 6 | OMN (part), NMM (part) |
D | 7 | CRP (part) |
D | 8 | CRP (part) |
D | 9 | LEA, LUM, PPP, P_C (part), NMM (part), MVH, OTN, ELE, OME |
D | 10 | GAS, P_C (part) |
E | - | ELY, GDT, WTR, CNS, TRD, OTP, WTP, ATP, CMN, OFI, ISR, OBS, ROS, OSG, DWE |

Table 5.2: Matching of NSTR commodity groups with GTAP sectors

Regional Data
Apart from national accounting data, CGEurope needs regional GDP and sectoral value-added data for the calibration of the benchmark year 2000. These data are available from Eurostat NewCronos. Unfortunately, NACE sectoral structure in NewCronos is not consistent with NSTR commodity structure. That is why we can only split value added between goods and service sectors and rely on country-level data for further sectoral split. Eurostat NewCronos contains such data only for the EU countries with reference year 2000. For the Balkan countries, Russia, Turkey, Switzerland and Norway additional data from the International Labour Organisation and national statistical offices are used. The indicators used are regional gross value added and employment by sector.

Trade
Information on interregional exchange of goods and services plays a key role in the CGEurope model. The ETIS-BASE dataset provides trade data for 11 commodities on region by region basis that will be used in CGEurope to calibrate the model. CGEurope, however, works with 12 commodities by adding a further commodity, services. No information is available for interregional flows in service trade from the transport models in TRANS-TOOLS. Interregional service flows are therefore generated in the calibration process using interregional goods trade data from ETIS and international service trade estimates from GTAP.
Transport Costs
Interregional trade cost data for all region pairs and transport modes are obtained from the TRANS-TOOLS freight model, i.e., the NEAC model. Changes of transport costs and times obtained from the freight model are inputs into CGEurope that determine the impact on production in each region, trade between regions, prices, and utilities.

Model Parameters
Model parameters determine the households’ preferences and market forms. They are derived from econometric estimations taken from the literature.

Formulation
CGEurope is a multiregional CGE model with utility-maximising households in each region representing final demand, and firms belonging to 5 industries representing the production sector.

In each region reside immobile households owning the regional stock of production factors (factors are as well immobile). Their income stems from regional factor returns as well as from an interregional income transfer that can have a positive or negative sign. Households spend their income for buying goods and services partly produced in their own regions and partly produced in the other regions.

Households' demand represents total final demand that means private as well as public consumption and investment. There is no separate public sector in the model, i.e., households have to be regarded as an aggregate of the private and public sector, their budget constraint is the consolidated budget constraint of the private and public sector in the region.

Households buy composite goods, composed of deliveries from all regions. The composite good produced by each industry is composed according to a two-level nested constant-elasticity-of-substitution (CES) index. On the upper level, customers choose between regions of origin, on the lower level they choose between varieties within regions of origin.

Firms in each region are subdivided into 5 industries:

A  Agriculture
B  Oil, crude oil
C  Mining
D  Manufacturing
E  Services

The way we model firms’ technologies is displayed in Figure 5.1. Each industry uses regional production factors, which are owned by the household, and several types of commodities as inputs in their production process. It is assumed that each firm uses outputs of one or several industries in the production process; the information about the cross-industry relationships is obtained from the national input-output tables. The demand by industry is split into the specific commodities produced by the respective industry according to a CES cost function that represents the production of the firm. These CES cost functions are characterised by two types of parameters: position parameters and elasticities for each commodity used in the
production in the industry. The former fix input-output coefficients at a desired point, given the input prices. The latter define how input ratios react on changing input price ratios.

At the next level, the demand of the firm for each commodity is split across regions of origin using Armington preferences for varieties of the industry outputs produced in each region.

The total price of each commodity at a destination is determined by the mill price of the firm in the region of origin and the interregional transport costs, which are paid by the firm that buys the commodity to the service sector in the region of destination. In the region of origin, total demand is split across varieties of the good produced in the region. The same composition for varieties is assumed for firms and households, such that their respective demand for a composite good can be merged into aggregated regional demand for that good. Due to free entry the price per unit of the good in a region is equal to the average cost.

On the output side of the firms, each sector is characterised by a constant-elasticity-of-transformation (CET) production frontier, allowing for multiproduct outputs of each industry. The CET functions depend on parameters in a similar way as the input CES functions, namely elasticities of transformation and position parameters. The former control how sensitively firms’ commodity output reacts on changes of relative prices, the latter fix the output shares at given benchmark data points for benchmark prices.

In the example in Figure 5.1, industry A produces two commodities. The total output of the industry is distributed across the two commodities that are produced by this industry according to the CET function. The output by commodity is then divided into product varieties using Dixit-Stiglitz diversification.

CGEurope is able to determine the impact of transport policies on demand for commodities in each region (and so on the commodity flows between regions), as well as to assess the welfare implications of these changes.
Figure 5.1: Modelling of the production side in CGEurope
Output

Commodity Flows
CGEurope is modelling the impact of transport cost changes on the volume of commodity flows by type of commodity, OD pair, and prediction year of each scenario. Comparing the scenarios one obtains the percentage effects on real trade flows of the specific scenario.

Real GDP per Capita
The Gross Domestic Product (GDP) per capita and the real GDP growth rate are the most common measures of the standard of living, wealth and economic growth. The GDP is a measure of the size and performance of a regional economy and its competitiveness.

CGEurope will compute the changes of real GDP by region and scenario year with respect to the reference scenario.

Equivalent variation
The normative side of the consumer theory, called welfare analysis, states that households gain benefits from the allocation of their income between consumption and savings. Consequently, how well off a policy change actually makes a household, depends on the effects of the policy change on prices, output, trade flows, income and how the household evaluates the benefits of these changes. This is assessed by the assumed utility function representing the consumer’s preferences. By comparing the utility level before and after the policy change, the welfare effects induced by the policy change can be measured. However, since utility levels only measure ordinal scales, they have to be translated into money metric terms. This can be done by applying the microeconomic concept of duality (see Deaton and Muellbauer, 1980) leading to a function, which gives the wealth (in monetary terms), required to reach a given level of utility when prices are constant. Using this (the so-called money metric indirect utility) function, one can measure the welfare change expressed in monetary units (Euro) induced by a policy change.

One of the well-known measures of welfare change based on this function and originating in Hicks (1939) is the Equivalent Variation (EV). Calling the situation before the policy change the benchmark, the EV of a policy change can be defined as the amount of money that must be added to the household’s benchmark income (everything else held constant at benchmark levels), in order to bring the household the same utility as under the policy change. Obviously, the EV is not the same as the income increase generated by the policy change. This would be so only if no variable influencing, utility but income changed. However, because of transport cost changes, other variables like prices and product varieties also change. The relative EV will be computed by CGEurope by region and scenario year.
5.2 Interactions between economy, energy system and environment, GEM-E3

Keywords: Linking, economic modelling, energy and environment

Reference: Panos Christides, Joint Research Centre, Seville

Objectives
GEM-E3 aims at covering the interactions between the economy, the energy system, and the environment. It is an applied general equilibrium model in which the world is divided into 18 zones that are linked together with endogenous trade. Each of the zones has the same model structure, but parameters and variables are zone specific. The economy is divided into 18 sectors. Four of the sectors are involved in the supply and distribution of energy and the remaining sectors are broad aggregates of the rest of the economy. The structure of the model is seen in Figure 5.2.

The production in each sector is modelled by using a nested constant-elasticity-of-substitution (CES) production function. The use of inputs and primary factors in each sector follows from a procedure involving several steps; at each step, inputs and primary factors are optimally combined according to a constant-returns-to-scale CES production function and the producer behaviour is modelled on the basis of standard assumptions about profit maximisation in a perfectly competitive environment.

Methodology
The two primary factors of production are capital and labour. The labour market is assumed to be perfectly competitive and total labour supply is determined by households that maximise their utility functions. For each period, the model endogenously allocates the available labour force over sectors. Capital is a quasi-fixed variable, and is defined in a way that allows firms to change next year’s capital stock by investing in the current year. It is further assumed that the stock of capital is immobile between sectors and countries.

Government activities are modelled almost in the same manner as the other sectors of the economy. Thus, the use of inputs is determined through cost minimisation. However, the remaining parts of government activities (expenditures, investment demand and tax levels) are exogenous. Financing of government expenditures is provided from nine different sources of government revenues: indirect taxes, environmental taxes, direct taxes, value-added taxes, product and export subsidies, social security contributions, import duties, foreign transfers and profits or losses from state-owned firms.

The households are modelled as one representative household, which can supply labour, save, invest and consume thirteen consumer goods. The representative household allocates its resources in an inter-temporal environment. The household’s consumption behaviour is derived from utility maximisation, and consists of two steps. Firstly, the household allocates its resources between future and present consumption, given the wage rate, the interest rate and the long-term time preference. Secondly, the household takes total consumption in a period as given and makes an intra-temporal decision about how to divide the total consumption between the different consumer goods in the economy.
The demand for products by the household, the producers, and the public sector constitutes the total demand. It is allocated between domestic products and imports, following the Armington specification. In this specification, cost minimising sectors and households use a composite commodity that combines domestically produced and imported goods, which are considered as imperfect substitutes.

The GEM-E3 model also distinguishes between goods imported from EU countries and those from the rest of the world. An index for optimal allocation of imported goods according to country of origin and price is calculated, and this index price is then used to allocate consumption between the imported and the domestically produced goods, as discussed above. It is further assumed that countries apply a uniform rule for setting export prices, independently of the country of destination. The Armington assumption implies that the various countries within the European Union can supply exports at different prices.

Data issues
The model has been estimated for the EU economy in 1995 and 2020, in all the scenarios of the study: baseline or business-as-usual (BAU), concentrated, diversified and uniform. The data come from EUROSTAT (1995 input-output table of the EU economy), and from the GEM-E3 model, which computes endogenously the model parameters for all scenarios in the year 2020.

Applications
The main types of issues that the model has been designed to study are:

- The analysis of market instruments for energy-related environmental policy, such as taxes, subsidies, regulations, pollution permits, etc., at a degree of detail that is sufficient for national, sectoral, and Europe-wide policy evaluation.
- The evaluation of European Commission programmes that aim at enabling new and sustainable economic growth, for example, technological and infrastructure programmes.
- The assessment of distributional consequences of programmes and policies, including social equity, employment, and cohesion targets for less developed regions.
- The consideration of market interactions across Europe, given the perspective of a unified European internal market, while taking into account the specific conditions and policies prevailing at a national level.
- Public finance, stabilisation policies and their implications on trade, growth, and the behaviour of economic agents.
- The standard need of the European Commission to periodically produce detailed economic, energy, and environment policy scenarios.

Policies that attempt to address the above issues are analysed as counterfactual dynamic scenarios and are compared against baseline model runs. Policies are then evaluated through their consequences on sectoral growth, finance, income distribution implications, and global welfare, both at the single zone level and for the EU taken as a whole.
The model is designed to support the analysis of distributional effects that are considered in two senses: distribution among European countries and distribution among social and economic groups within each country.

The former issues involve changes in the allocation of capital, sectoral activity and trade and have implications on public finance and the current account of member states. The latter issues are important, given the weakness of social cohesion in European member-states, and regard the analysis of effects of policies on consumer groups and employment. The assessment of allocation efficiency of policy is often termed “burden sharing analysis”, which refers to the allocation of efforts (for example taxes), over member-states and economic agents. The analysis is important to adequately define and allocate compensating measures aiming at maximising economic cohesion. Regarding both types of distributional effects, the model can also analyse and compare coordinated versus non-coordinated policies in the European Union.

Technical progress and infrastructure can convey factor productivity improvement to overcome the limits towards sustainable development and social welfare. For example, European RTD strategy and the development of pan-European infrastructure are conceived to enable new long-term possibilities of economic growth. The model is designed to support analysis of structural features of economic growth related to technology and evaluate the derived economic implications for competitiveness, employment, and the environment.

Figure 5.2: Structure of the GEM-E3 model
6 Assignment best practice

6.1 A rail punctuality model, Copenhagen

Keywords: schedule-based, public transport assignment, reliability, regional

Reference: Prof. Otto A. Nielsen, CTT, DTU

Objectives
The Copenhagen Suburban Rail Company (DSB S-tog) has so far only measured train reliability (cancelled trains) and punctuality (delayed trains). However, it has long been desired that also passenger delays should be measured. This is defined as the delays passenger experience when arriving at the destination compared to the arrival time according to the planned time table. The purpose of quantifying rail delays is two-fold:

1) to be able to deliver more detailed reports on passenger delays to the Ministry of Transport and Energy;
2) to provide a better basis for planning in the rail company. This includes designing timetables and disposing the rolling stock with respect to passenger flows.

Methodology
Even though delays have great importance for people’s valuation of public transport as shown in the VoT research, evaluation and forecasts of punctuality and reliability of railway systems have in practice – if at all – been computed for trains, not for passengers. Furthermore, when passenger delays have been calculated, the underlying models have not explicitly considered how passengers’ reacts on the delays they experience on-route when they are travelling. Passenger delays differ however from train delays due to the following reasons;

1. The number of passengers per train varies. Since train delay is mainly a function of the number of passengers (door interchanges) and capacity utilisation\(^4\) (risk delays from one train propagate to other trains), it is likely that trains with more passengers in the rush hours are more likely to be delayed than trains with fewer passengers outside the rush hours. Trains in the intensely used part of the network tend also to have more passengers and be more sensible to delay propagations. Train delay measurements tend accordingly to underestimate the delays that passengers experience.

2. If passengers transfer between train lines, the situation is even more complex. If the next train line is reached anyway, then the passengers may only consider the delay of this train line as a problem (except the annoyance factor on the first train line). However, if the connection is lost, then the delay may be much larger than just the delay of the arriving train (Bates et al., 2001). Some passengers may even obtain a better connection, if a prior and more convenient train connection is delayed, whereby the passenger can board this and reach the final destination before planned.

\(^4\) The train intensity compared to the amount of trains that the infrastructure can handle
3. The same track may be served by many train lines. Passengers on short trips may not experience a delay, if they can take another train at the planned time leading to the same destination at the same time as with the planned rail service.

Even though a utility function may have been estimated based on SP data, it is accordingly not trivial how to apply this in a schedule-based route choice model for public rail transport.

The applied third generation model, see Section 9.3.4 in CTT (2007), assumes that passengers are planning their optimal desired route according to the official timetable. However, if delays occur over a certain threshold during the trip, the passengers are then assumed to reconsider the route at that point in time and space along the route. If a train is completely cancelled, then they reconsider their choice without a threshold.

The main benefit of the model is that it is more realistic and precise than the prior generations of passenger delay models. The disbenefit is that it is more complicated to implement, and that the calculation time is larger, since the route choice model has to be re-run at the point in time and space where the schedule is delayed.

The model uses the optimal paths (or paths taking expected delays into account) in the planned timetable for two reasons 1) to compare planned travel times with the ones in the realised timetable, and 2) to estimate an a priori path choice strategy for the passengers. A 1st or 2nd generation passenger delay model is therefore used to calculate the initial solution for the 3rd generation model.

A core assumption is that the paths are stored as a sequence of lines (each with a specific run) and transfer stations. The passengers are assumed to try to follow the same sequence of transfer stations and lines as planned, but they may use different train runs by each line. This is somewhat similar to a rule-based assignment. In order to make this feasible, the rule-based network and diachronically graph interacts by pointer structures that are built in memory as the graph is built (somewhat similar to the principles in Nielsen et al., 2004). This is described further in Nielsen and Frederiksen (2007). To ease the formulation of the model, it distinguishes between whether the planned routes contain transfers or not (Nielsen and Frederiksen, 2005).

Simplifications in the first phase of the work
The complexity of timetable-based public transport networks – and the size of the underlying calculation graph – quickly becomes extremely comprehensive. This is due to the time dimension, where all departures for each line must be handled. Therefore, some simplifications were decided;

- Only the suburban rail system was considered.
- The model is deterministic concerning the passengers’ choice functions (opposite to the prior references by Nielsen), this made it possible to analyse the impact of delays exclusively without mixing this with the other stochastic elements5.

5 A new version has now been implemented that includes overlapping routes (Probit-based error term) and random coefficients as in Nielsen et al. (2001).
The model runs on a station-to-station OD matrix. Only a daily average time-space OD matrix is presently available, whereby the choice functions cannot be multi-class as in, e.g., Nielsen (2000).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{\text{train}}$</td>
<td>Run time (may be subdivided into different sub-modes). 25 DKK per hour.</td>
</tr>
<tr>
<td>$T_{\text{delays}}$</td>
<td>Inconvenience due to delay time (only relevant in VoT appraisal, since the passengers in the present model are not assumed to know the delays a priori). 55 DKK per hour.</td>
</tr>
<tr>
<td>$T_{\text{wait}}$</td>
<td>Waiting time in minutes (the first boarding assumes a fixed small number of minutes), i.e. the difference departure time and arrival time at a station minus transfer time. 43 DKK per hour.</td>
</tr>
<tr>
<td>$T_{\text{transfer}}$</td>
<td>Transfer times in minutes (walking time in connection to transfers). 43 DKK per hour.</td>
</tr>
<tr>
<td>$T_{\text{hidden}}$</td>
<td>Hidden waiting time (difference between desired departure time and the chosen, minus the waiting at the station for the first boarding). 13 DKK per hour.</td>
</tr>
<tr>
<td>$P_{\text{transfer}}$</td>
<td>Fixed transfer penalty (extra discomfort and annoyance per transfer). 7 DKK per transfer.</td>
</tr>
<tr>
<td>$l$</td>
<td>Distance in km.; Proxy for the complicated Copenhagen Zonal-based ticket fare system, which despite the complexity is fairly correlated with trip length</td>
</tr>
</tbody>
</table>

Table 6.1: Variables in the choice functions. 1 DKK was 7.6 Euro in 2004.

Practical use of the model
The OD matrix is based on a yearly traffic count of all passengers. It is segmented on one-hour intervals, within which demand is assumed uniformly distributed and segmented into smaller intervals. Desired departure times within these intervals are simulated randomly for each OD pair (launches). The urban rail stores 3 variants of the timetables in their data warehouse:

1. The published (norm) timetable, i.e., the main principal timetable.
2. The planned timetable. This is the specific timetable that is planned for the specific day, this differs from the published timetable by including planned and announced changes, including delays and cancellations, e.g., for a planned track repair project.
3. The realised timetable. This describes the actual operation during the day, including non-planed cancellations, delays, etc.

Typically, the realised timetable is compared to the planned, since the passengers are assumed to be aware of the announced changes. However, the planned timetable can also be compared

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\textsuperscript{6} A new project is developing a time-segmented OD matrix estimation method based on counts from counting trains.

\textsuperscript{7} It is quite common that the planned timetable differ from the published somewhere in the network, especially in the evenings hours and weekends, where most planned maintenance occurs.
to the published in order to evaluate the passenger inconvenience (time loss) due to planned changes. The costs of not announcing planned delays can in addition be evaluated by comparing 3) with 1) and base the planned route on 1) instead of 2).

Facts about the implementation
The network includes 104 zones (or rather stations), 42 main time intervals, within each 1 to 5 minutes launches are simulated (most detailed in the rush hour due to more frequent departures and higher demand), approximately 60,000 OD elements (sparse matrix), and 1,200 runs per day. The resulting calculation graph includes approximately 200,000 links and 120,000 nodes.

The assignment programme and module that control input and output from the data warehouse was developed in C++. The data warehouse was built in Microsoft’s SQL and run on a Microsoft’s SQL Server 2000. The module that handles input and output between the calculation model and the data warehouse was developed in C# under Microsoft’s .Net development platform.

Data issues
The model was implemented in order to run on the data warehouse for rail delay data used by the Copenhagen Suburban Rail Company (DSB S-tog). For a given day this automatically collects and stores the planned as well as realised timetable including delays and cancellations. The assignment model is run during the night after the data warehouse has loaded and prepared the timetable data. The result is a daily measurement of passenger delays. All information is stored (each run with each line, as well as all transfers), whereby information can be aggregated to any level the user wants.

Applications
First of all, the tests and use of the models proof that it is practically feasible to run a model of the type outlined above. The calculation time depends on the number of delays (recalculation of routes). So far the interval of calculation times has been between 10 and 20 minutes. This was much faster than the contractual requirement (8 hour calculation time over night).

Overall results
Table 6.2 based on Seest et al. (2005) illustrates as an example the summary of results for one day (in this case June 7th, 2004). The reliability describes trains not cancelled, while the punctuality describes the percentage of passengers who reach the final destination with maximum 5 minutes delays. For delayed passengers, the average delay is also given. Finally, the percentage of passengers who arrive earlier is given (if they can board a delayed train where they normally should have waited until the next departure, and where they thereby reach their final destination prior than what would have been the case due to the planned timetable).

The first row in the table shows the train reliability and punctuality. When this is compared to the following rows for passenger reliability it can be seen that the passenger punctuality is much worse than the train punctuality. As an example, only 4.6% of the trains are delayed more than 5 minutes in the morning the specific day, even so at least 16.0% of passengers are delayed (given a 50 second threshold).
<table>
<thead>
<tr>
<th>Treshold (sec)</th>
<th>Train reliability / punctuality</th>
<th>Morning</th>
<th>Day hours</th>
<th>Afternoon</th>
<th>Evening</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Reliability</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>98.1</td>
<td>99.7</td>
</tr>
<tr>
<td></td>
<td>Punctuality (no delays)</td>
<td>84.0</td>
<td>84.3</td>
<td>80.5</td>
<td>90.3</td>
<td>86.8</td>
</tr>
<tr>
<td></td>
<td>of this before time</td>
<td>15.7</td>
<td>14.1</td>
<td>17.3</td>
<td>9.3</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>Average delay (min)</td>
<td>8.2</td>
<td>7.9</td>
<td>9.0</td>
<td>7.9</td>
<td>7.7</td>
</tr>
<tr>
<td>150</td>
<td>Reliability</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>98.1</td>
<td>99.7</td>
</tr>
<tr>
<td></td>
<td>Punctuality (no delays)</td>
<td>82.7</td>
<td>83.4</td>
<td>79.8</td>
<td>88.9</td>
<td>86.6</td>
</tr>
<tr>
<td></td>
<td>of this before time</td>
<td>15.3</td>
<td>13.9</td>
<td>16.8</td>
<td>22.4</td>
<td>24.8</td>
</tr>
<tr>
<td></td>
<td>Average delay (min)</td>
<td>8.4</td>
<td>7.9</td>
<td>9.1</td>
<td>8.2</td>
<td>7.7</td>
</tr>
<tr>
<td>248</td>
<td>Reliability</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>98.1</td>
<td>99.7</td>
</tr>
<tr>
<td></td>
<td>Punctuality (no delays)</td>
<td>81.3</td>
<td>82.4</td>
<td>79.2</td>
<td>87.9</td>
<td>86.1</td>
</tr>
<tr>
<td></td>
<td>of this before time</td>
<td>14.9</td>
<td>13.7</td>
<td>16.5</td>
<td>22.1</td>
<td>24.7</td>
</tr>
<tr>
<td></td>
<td>Average delay (min)</td>
<td>8.9</td>
<td>8.1</td>
<td>9.4</td>
<td>8.8</td>
<td>8.3</td>
</tr>
<tr>
<td>400</td>
<td>Reliability</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>98.1</td>
<td>99.7</td>
</tr>
<tr>
<td></td>
<td>Punctuality (no delays)</td>
<td>80.1</td>
<td>80.7</td>
<td>78.8</td>
<td>87.0</td>
<td>85.4</td>
</tr>
<tr>
<td></td>
<td>of this before time</td>
<td>14.6</td>
<td>13.4</td>
<td>16.2</td>
<td>22.0</td>
<td>24.2</td>
</tr>
<tr>
<td></td>
<td>Average delay (min)</td>
<td>9.4</td>
<td>8.6</td>
<td>10.1</td>
<td>10.0</td>
<td>8.6</td>
</tr>
</tbody>
</table>

Table 6.2: Example on result summary for one day. All numbers are given in percents

The passenger reliability is much better than the train reliability. This is not surprising though, since some trains are cancelled, or the runs are shortened as the train returns from a station before the end station to reconstruct the schedule, whilst most passengers eventually will reach their final destination. The few passengers who do not arrive in the evening hours (1.9%) are due to cancellation of the last train or missed transfers to this. They have to take a night bus or taxi or walk to get home, which is outside the present model network.

An interesting aspect is that quite many passengers reach their destination before planned due to irregularities in the realised timetable. Measured in percent this is more or less equal to the number of delayed passengers (15.7% in the morning). But the benefit is typically lower than the disbenefit for delayed passengers, whereby the passengers in average are delayed (in the morning on average 8.2 minutes this specific day). One should also remember that delayed time have a higher value than the value of saved travel time when arriving earlier than expected.

The table also illustrates the importance of the threshold (when passengers begin changing route). The punctuality is improved the sooner passengers starts reconsider changing route (i.e., the lower threshold). The significance of the threshold is maybe lower than one could expect. This may be explained by the fact that a great part of the passengers (about 90%) in the Copenhagen rail system do not transfer from train to train. When trains are delayed they do not have better alternatives than staying in the delayed train. That the model allows
passengers to reconsider routes may therefore not result in that the passenger is actually finding a better route. The threshold may therefore have greater importance if the case study had been extended to include other public transport modes (metro, regional train, local rail lines) and ultimately also the bus network.

According to the passenger punctuality model, passengers will not change their route of travelling until a certain threshold of delay has been reached. However, on some stations or OD relations, passengers will just take the first train in the right direction. This phenomenon is characteristic for short journeys with high train frequency and is observed in the central Copenhagen with a train frequency of approximately 2 minutes in each direction. The phenomenon might, however, also be observed at OD relations with a lower frequency. Further work is necessary to estimate the correct threshold of delay to make passengers reconsider their route. Finally, the table shows the importance of the segmentation of the OD matrices (here 5 minutes versus 10). As shown this does not change the results much (within each time slice, demand is assumed uniformly distributed).

Example on analyses along a line

Figure 1 illustrates the results along a given train run. The full-drawn (blue) line is the passenger flows on the delayed run (running from 8:12-9:39) and the dotted (blue) line is the planned (8:30-9:25) (Seest et al. (2005)). The passenger flow increases as the train approaches the central part of Copenhagen (Dybbølsbro-Nørreport), after which it drops when the train is leaving the city again (the train is running from a suburb through the city to another suburb). The delayed train has more passengers in this case since the passenger arrival process will accumulated more passengers at the platform at the same time as no alternative routes exists for this line. The smaller difference between passengers between Hvidovre and Nørreport can be explained with the availability of parallel suburban rail lines along this segment.

Figure 6.1: Number of passengers in a specific train run, as a function of stations

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8 It is only the regional train that has fairly easily accessible delay data in an electronic form that can easily be combined with the urban rail data. The regional train is a good alternative among two segments of the suburban rail network.

9 Valby just after Hvidovre is a large junction where 3 other train lines converges.
6.2 An assignment model for car travellers in Copenhagen

Keywords: route choice, assignment, mixed logit, equilibrium, regional

Reference: Prof. Otto A. Nielsen, CTT, DTU

The purpose of this model has been to provide as precise assignment as possible in a number of models in the Copenhagen region. Three examples are assessment of a Harbour Tunnel in 1998 (see Paag et al., 2002), modelling of GPS data in the AKTA experiment in 2003 (Nielsen, 2004b), and environmental assessment of road pricing in the IMV project in 2006 (see Rich and Nielsen, 2007). Here we will focus on the earliest application since the last two are more state of the art than best practice as they rely on GPS.

Here we present a large-scale stochastic road traffic assignment model for the Copenhagen region. The model considers several classes of passenger cars (different trip purposes), vans and trucks, each with its own utility function on which route choices are based. In application, the different classes and types of vehicles influence all the speed-flow relationships on links within an equilibrium framework. Sub-models for intersections and roundabouts describe queues and geometric delays.

Objectives
This example presents the formulation, estimation and calibration of a large-scale stochastic multi-class road traffic assignment model for the Copenhagen Region. The work was carried out in order to evaluate the Copenhagen Harbour Tunnel Project visualised in Figure 6.2.

![The Harbour Tunnel](image)

Figure 6.2: The central Copenhagen Area and location of the Harbour tunnel
The Harbour Tunnel project included further development of the pre-existing Ørestad Traffic Model (OTM), as well as the route choice model, re-estimation of the modal split model for person-trips, estimation of new goods-vehicle matrices and development of a new trip-distribution model for goods-traffic. Paag et al. (2002) describes the project and its background in further detail.

Methodology
The choice between two main modelling approaches were considered at the beginning of the project (see Figure 6.3):

- **Traditional nested logit model**
  - Mode choice, etc.
  - Car users: Choice of tunnel
  - Non tunnel users
    - Assignment on network without tunnel
  - Tunnel users
    - Assignment on network with tunnel. Trips not using the tunnel are reassigned until they use the tunnel
  - Heuristic to update travel times

- **Tunnel choice as part of assignment**
  - Mode choice, etc.
  - Route choice model, with willingness to pay included in the utility function

**Figure 6.3: Main modelling approach concerning the choice of tunnel**

- A conventional nested logit model for the choice of route: through the tunnel (with or without toll) or using the alternative bridge(s) (no toll) followed by a separate assignment of routes through the tunnel and over the bridges, respectively;

- A combined stochastic assignment model for route choice, including willingness to pay and tunnel choice.
The advantages of the stochastic assignment model compared to the logit model were:

- The tunnel is a small part of the transportation infrastructure in Copenhagen. Therefore, the choice of travelling through the tunnel is closely interrelated with the choice of route. The choice set is a huge number of possible routes, and can therefore not easily be represented by a discrete choice model.

- By dividing the travellers into tunnel users and non-tunnel-users before assignment, it would not be theoretically and practically possible to achieve consistency between the utility functions in the route choice models and the model for choice of travel through tunnel or not. It would furthermore be difficult to model user equilibrium considering congestion effects, if two separate assignments were carried out.

- In practice, it would be difficult to force the route choice model to assign routes through the tunnel, for the group of travellers determined in the logit model as tunnel users. The bridges that are the alternatives to the tunnel cannot be ‘closed’ in the assignment procedure, as some of the tunnel users also need to use one of the bridges. Therefore an iterative procedure would be needed in the assignment algorithm to reject ‘forbidden’ routes, until routes were forced to use the tunnel. This would result in an awkward software program with a large increase in calculation time. It would also result in a model that would be specific for this single infrastructure project.

- On the other hand, a stochastic assignment model could be used for wider examinations of willingness to pay, for instance toll roads, road pricing or payment for other new infrastructure projects. In addition, the software and the theoretical foundation would be available for use in other areas.

Based on its methodological and practical advantages, it was decided to proceed with the stochastic assignment model. Technically this is the first time a model of this type has been estimated based on stated preference (SP) data and put into practice on a large traffic network. The basic methodological framework for the assignment model follows the Stochastic User Equilibrium (SUE), see Chapter 9 in CTT (2007). However, it has been extended in various ways to include more complex utility functions (Nielsen, 1996), user classes (Nielsen, 1998), and delay functions (Nielsen et al., 1998).

Each user class chooses routes according to its own utility function. But the time-components in the utility depend on the choices of the other classes due to congestion at link level and intersection priorities. At link level, the traffic in each direction influences each other on two-lane roads by a modified BPR-formula (Nielsen et al., 1998). In addition, the truck fractions calculated from the assigned traffic influence the capacity (Nielsen et al., 1998). The links are divided into a number of types, each with its own speed-flow relationship. At intersection level, separate models describe different intersection types (ramps, unprioritised, prioritised, signalised, roundabouts and other types). Turn movements influence each other when relevant (Nielsen et al., 1998). In signalised intersections, the effects of protected phases and signal co-ordination are
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included (by a platooned arrival model). In addition geometric delays are modelled; that is the
difference between modelled speed according to the speed-flow curves at link level and the
speed during acceleration and deceleration to and from intersections.

The model is solved by simulation using the Method of Successive Averages (MSA).

Generalised utility function

The utility function (which defines the route choice cost by summing for each road link) can
be written as:

\[ U_i = (\beta_t + \xi_t) \cdot \text{time} + (\beta_c + \xi_c) \cdot \text{cost} + \varepsilon_a, \]

where:

- \( \beta \) are coefficients that multiply time and cost;
- travel time is dependent on the amount of traffic both on roads and in junctions, and is
  therefore influenced by the total number of vehicles, independent of their user class;
- \( \xi \) represents systematic variation of the coefficients (i.e., \( \xi_t \text{time} \) and \( \xi_c \text{cost} \) are error
  components);
- \( \varepsilon \) represent random variations at the arc level. Gamma-distributed \( \varepsilon \)'s were used for
  application in the present study. The Gamma distribution is reproductive in mean and
  variance just like the Normal distribution, given that the variance is linked to the mean
  by a fixed coefficient of variation (Nielsen and Jovicic, 1999), and it has the advantage
  of being non-negative.

It is emphasised that the inclusion of the distributed coefficients (\( \xi \)) improves the models’
ability to describe differences in drivers’ preferences. This results in a more accurate descrip-
tion of their choice of route than given by conventional logit models, where differences in
choices are assumed to be caused purely by random variation (\( \varepsilon \)).

Data issues

Estimation of the coefficients in the generalised cost expression was based on SP data. The
model has been calibrated on revealed preference (RP) data.

Applications

As mentioned above the model has served as assignment tool in several transport models. One
consideration though is whether the complicated model is necessary. It has been seen in the
applications that it is very important to have a detailed assignment in a dense network with
many competing routes. Furthermore, it could be important to allow for congestion effects
and multiple-users classes. On the other hand, if these effects are not important it might be
more effective to use a simpler assignment procedure.

In the harbour tunnel case, the model was used on a full-scale network of Copenhagen with
2,369 nodes/intersections and 3,462 links. This results in 6,108 directed links (forward and
backward direction), 12,073 ‘pseudo nodes’, and 19,111 turns. The trip matrices for the five
trip purposes each have 297x297 elements.
A series of tests were carried out in order to make it probable that the assignment model converged. The performance was rather similar to the results regarding the single-class assignment model in Nielsen et al. (1998). After a careful examination of different types of convergence criteria, it was decided to run the model for 250 iterations, which secured convergence with certainty. This took about 10 hours on a 180 MHz Pentium Pro PC. The three time-periods (7-9, 15-17, and the rest of the day) are run in parallel. The full modelling complex needs 5 iterations to converge between demand and assignment (supply), but as the assignment model is run with fewer iterations in the initial steps than in the final step, the whole model can be run in 24 hours, even on this quite limited hardware.

It is difficult to use the total traffic on all roads to evaluate the model behaviour, as this is the sum of many bundles of routes connecting many zone-pairs. Thus, a good fit at link-level is only a necessary but not a sufficient condition for a good model. The implemented software has therefore a facility to save trees going out from a zone, bundles between zones, ‘sheaves’ of routes passing a selected link or any combinations of these options. By doing this, it is possible to examine the route choices in more detail and reveal problems that otherwise would have been overlooked.

An example is routes to and from the airport of Copenhagen (see Figure 6.4 for the passenger traffic in the morning rush hour) that can be compared to a prior traffic survey. In the study this was done for other user classes as well to see how the route choices differed between the classes.

The split between the two main routes – the Motor Ring Road on the left and the urban arterial on the right – was due to the error components. Without these, no split between the two main routes was achieved. The variations in the routes through the city on the bottom right of the figure are on the other hand due to the conventional error term in SUE.

In a previous version of the model, the route choices for trucks did not distinguish between different vehicle types’ decelerations and accelerations in intersections (Geometric delays). In this case, the model assigned too much traffic into the city and too little to the motorway network (for the two bundles presented 24% and 64% traffic through the city respectively). When the model was modified to describe differences in vehicles’ decelerations and accelerations, the figures changed to 14% and 55%. This improved the performance quite significantly at an aggregate level (total flows of each vehicle type).
Figure 6.4: Work-based trips between Copenhagen Airport and the city of Farum
6.3 Toll road in Eindhoven

Keywords: operational, demand model, regional, toll

Reference: ir. D.H. van Amelsfort, Goudappel Coffeng BV

Around the west side of the city of Eindhoven, half of a ring has been created as motor highway. This western ring road will be extended as a 4x2 connection in the future. This solves the traffic problems at the highways around Eindhoven for the main part. At the east side of Eindhoven, there is currently not a ring road. Therefore, the traffic with an origin or destination at the eastside of Eindhoven has to use the inner city ring or different other short cuts at secondary roads. This leads to unnecessary use of the main road in the city of Eindhoven.

In this toll study two network scenarios for the construction of a eastern ring road (a 2x2 motor highway in tunnels) have been investigated:

- A short variant; the northern tunnel segment starts at the A50/A58 and the southern tunnel segment is connected with the A67;
- A long variant; this is the short variant with an extension at the south side between A67 and A2.

In Figure 6.5 and 6.6 the network scenarios are shown.

![Figure 6.5: Short network scenario](image)

The new motor highway will become a toll road. Five toll alternatives were defined each with different toll payment locations. Within each toll, alternative several price levels have been defined to investigate non-linear effects.

Model description

In this toll study, use has been made of the static traffic model of the region of Eindhoven. The base of this regional model is a multi-modal system for the total region with its 20 communities. The toll scenarios have only been calculated with the model for car and trucks,
where trucks are split up in light goods vehicles (LGV) and heavy goods vehicles (HGV). In the study, only route choice effects have been considered. Other behavioural effects like mode choice, departure time choice, destination choice, or the number of trips have not been considered.

In Figure 6.6, the long network scenario has been shown.

![Figure 6.6: Long network scenario](image)

Toll studies in Scandinavia and France have shown that these behavioural aspects are negligible except for departure time choice.

The model describes the following periods:

- Morning peak (07.00-09.00 hour);
- Evening peak (16.00-18.00 hour);
- Rest of the day (18.00-07.00 hour and 09.00-16.00 hour).

In both peak models, a capacity restraint multi-user class assignment has been applied, containing junction modelling. To assign the cars and trucks at the same time in a capacity restraint assignment it is necessary to take into account that trucks use more capacity than cars. Therefore use has been made of the PassengerCarEquivalentUnit (PCU). The PCU’s for car, LGV, and HGV are respectively 1, 1.5 and 2.5. The model for the rest of the day is assigned with the Burrell-method.

To calculate the revenues for each alternative a macroscopic dynamic assignment model is used. Therefore, the 2-hour peak OD matrices have been split up in 8 quarters of an hour. Apart from costs also comfort, guaranteed travel time and status are important. This is the reason that apart from value-of-time also willingness-to-pay has been taken into account.
Figures and tables
Figure 6.7 shows the OD relations that make use of the new toll road. It can be concluded that these are mainly travellers with an origin or destination at the east side of Eindhoven.

Figure 6.7: Long network scenario

In Figure 6.8, the five different toll alternatives are shown.

Figure 6.8: Five toll scenarios
The following factors for the value of time (VoT) and willingness to pay (WTP) for comfort have been used.

<table>
<thead>
<tr>
<th>Application</th>
<th>VoT</th>
<th>WTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>8,28</td>
<td>12,59</td>
</tr>
<tr>
<td>Business</td>
<td>29,79</td>
<td>45,32</td>
</tr>
<tr>
<td>Other</td>
<td>5,78</td>
<td>8,80</td>
</tr>
<tr>
<td>Light goods vehicles</td>
<td>23,13</td>
<td>33,54</td>
</tr>
<tr>
<td>Heavy goods vehicles</td>
<td>39,96</td>
<td>56,74</td>
</tr>
</tbody>
</table>

Table 6.3: Value of time and factors of willingness to pay (euros per hour)

Application
The following questions that had to be answered in the study were:

- Which toll regime maximises the revenues? Moreover, what are these revenues?
- Which toll regime minimises the total congestion on the network?
- What are the traffic intensities and the effects at the secondary network?

The questions above have all been answered in a clear way with the used traffic model system. Apart from the results in numbers, the graphical presentation of the calculations has been very useful to understand the outcomes. In general, the results show that if alternative routes are available, then the toll road will be used less. If there is only choice between paying toll or queuing up, the toll road will be used more which leads to higher revenues, but also to higher traffic intensities on the secondary network.
7 Mode specific models

7.1 UK national rail model

Keywords: Strategic, rail, assignment, national

Reference: Faber Maunsell

The UK national rail model (NRM) is one element of the UK multi-modal modelling package, which is part of the basis for the Government’s Ten Year Plan for transport. The purpose of the modelling package is to assess the impact of various transport policies. Consequently, the national rail model is a strategic model illustrating effects of policy changes or changes in rail services to demand differentiated by corridors and conurbations.

NRM includes five key elements: A demand model, an assignment model, a user interface, a fares model, and aggregation modules. The latter converts matrices from the aggregated demand model to the detailed level of NRM and generalised costs from NRM to the aggregated model elements. The model includes 1328 zones, the entire rail network and all stations.

The rail demand model produces detailed rail demand matrices (by zones and directions) disaggregated by purpose, car ownership, and time periods. The input for the model is aggregated matrices (e.g., aggregated passenger models including mode choice) from other elements of the modelling package as well as base year matrices and distributions of traffic by time period.

The rail demand model includes rail growth within NRM rather than within the aggregated passenger models. The aggregated passenger models are used as cross-sectional tools to estimate responses to cost changes. In order to avoid double counting, the increase in rail trips attributed to time series is kept entirely within NRM.

The changes in demand for rail over time are based on income elasticities and time trends. The elasticities are disaggregated according to three market segments (business, commuter and leisure) and four different areas (South-East London, London Intercity, South-East non-London, and other), giving twelve different income elasticities in total. GDP forecasts are based on advice from HM Treasury.

The rail assignment model is the core part of NRM. In the model, the rail demand matrices are assigned to the rail network producing passenger loads on individual routes and lines. Furthermore, the model produces total passenger kms as well as generalised costs, which are used in the aggregated demand models. The generalised costs include in-vehicle time, wait time, access/egress time, fare, crowding, and interchange.

NRM includes a physical network representing all lines and stations currently in use. In order to provide flexibility of future enhancements of the model all new lines and stations under consideration for implementation for the next 20 years are included as well. By coding the
network at this level of detail it enables greater flexibility to change operational stopping patterns in the future. By providing a complete base-year representation of the network, and as far as possible the future year changes, the model can be run through the user interface without requirement of network expertise. The network link types used in NRM are:

- Centroid connectors to represent access times to the rail network
- Connecting walk links between rail lines at stations
- Links of all rail lines

Link lengths are in kilometres, whereas lengths of centroid connectors are weighted distances, which takes into account the proportions of trips using walk, bus or car as feeder mode. To differentiate between the various types of rolling stock used on the network, a number of vehicle types have been used. Identifying different types of rolling stock used and their capacity is important, as this enables the model to reflect crowding effects and evaluate emissions.

The transit lines coded in the model consists of nearly all services operating in the UK in the summer of 1999/2000 timetable. The model includes all rail services split in morning peak (7 AM to 10 AM) and inter peak (10 AM to 16 AM). The model represents the normal pattern of services in terms of trains per hour. This required some simplification, particularly in the peak period where services, although more frequent, tend to be less regular in relation to their arrival pattern.

The assignment is carried out in EMME/2 and is thereby based on the theory of optimal strategies formulated by Spiess and Florian (1989). A strategy is a set of rules that allow a passenger to reach the destination. The number and type of strategies that a passenger may choose from depend on the information that is available during the trip. In NRM it is assumed that passengers’ route choices are based on the information available at stations.

![Figure 7.1: Example rail network](image)

**Line 1**
(headway=12 min)

- 25 min

**Line 2**
(headway=12 min)

- 7 min
- 6 min

**Line 3**
(headway=30min)

- 4 min
- 4 min

**Line 4**
(headway=6min)

- 10 min

Node

**Figure 7.1: Example rail network**
An example is: Take next train on line 1 or 2, if line 1 is taken then exit at station Y, otherwise take line 2 to station Z and transfer to line 3 or 4 for station Y (see Figure 7.1). The public transport route choice is hypothesised as ‘How can one find the path from X to Y that minimises the expected travel time?’ By doing this the approach moves away from the concept that a passenger selects a single path from a set of possible routes. A passenger actually chooses a set of paths and then the first vehicle to arrive determines the path actually used.

The waiting time is calculated at each node by assuming that passengers wait on average half the arrival frequency. The line probability, the chance of a line being used, is the ratio of its frequency divided by the combined frequency. Suppose that in the example one hundred trips are assigned. The result is shown in Figure 7.2. This example shows how the algorithm achieves a multi-routing effect based on alternative strategies to reach the destination. It also highlights the importance of the frequency of services and the wait times estimated for each service on the routing through the public transport system.

**Line 1**
(headway=12 min)
50 trips

**Line 2**
(headway=12 min)
50 trips 50 trips

**Line 3**
(headway=30min)
0 trips 8 trips

**Line 4**
(headway=6min)
12 trips

**Node**

**Figure 7.2: Distribution of trips by optimal strategy**

EMME/2 requires a number of parameters to be specified prior to the assignment. The main parameters are:

- Representation of service headway through effective headway.
- Wait time factor, which reflects the proportion of the headway that travellers will wait on average.
- Wait time weighting to reflect passenger perceptions of walking time to the rail system.
- Boarding times at interchanges.
- Boarding time weighting to reflect the propensity to interchange at individual locations.
An effective headway adjustment factor is calculated to reflect the fact that waiting time for infrequent services is normally perceived as less than half the headway. With inter-urban services passengers will time their arrival at the station to catch specific timetabled trains and this is reflected in the model in order to prevent excessive wait times being generated. The wait time factor used in the model is 0.5 and is applied globally to all services but to an effective headway rather than the actual headway.

Boarding times are used to reflect the potential for interchanges, and ease of interchange at certain stations where station facilities in terms of services such as waiting rooms and catering make interchanges more comfortable. Also taken into account in setting the individual boarding times is the degree to which timetables have been constructed to make connection times better at certain locations. Each node, or station, in the network has a boarding penalty allocated to it with a general boarding penalty of 5 minutes for light rail stations and 10 minutes for all stations with national rail services. These are set to deter station interchanges. Specific boarding times for certain station were calibrated individually.

Finally, a number of parameters are set specifically in relation to NRM in order for the model to include, e.g., capacity restrictions. First of all the journey time is made dependent on the amount of traffic by multiplying the ‘free flow’ journey time with a crowding factor. This factor is 1 when the number of passengers is below the number of seats in the train, and increasing with increasing numbers of passengers depending on the number of seats and areas for standing.

EMME/2 is then used in an incremental assignment. With N the determined number of iterations in the assignment, 1/N of the demand is assigned to the network in the first iteration based on ‘free flow’ journey times. In following iterations crowding factors are calculated, journey times are adjusted and another 1/Nth of demand is assigned according to weighted averages of journey times. The iterations end when all demand is assigned to the network.

The capacity used for calculating the crowding factor is based on the frequencies of individual lines and the capacity of the rolling stock. Also, the calculation of waiting times is based on frequencies with adjustments to include effects for long headways. The waiting time is calculated as 0.5 of the effective headway, which is determined by

\[
E = \begin{cases} 
\text{headway, if headway}<15 \text{ min} \\
0.5 \times \text{headway} \times (1,81042 - 0.00563 \times \text{headway}), \text{if 15 min}<\text{headway}<60 \text{ min} \\ 
0.5 \times \text{headway} \times (1,40671 - 0.00262 \times \text{headway}), \text{if 60 min}<\text{headway}
\end{cases}
\]

There is a specific user interface for NRM making it possible to change settings relevant for the rail model. Changes can be made to service frequency, stopping pattern, rolling stock, run times and fares. Other more general settings like population, level of income, etc., is set in other elements of the model package. The user interface does not allow changes of the network. Instead, the network includes lines and stations currently in use or under consideration for implementation in the next 20 years.

The fares model provides a representation of rail fares on a point-to-point basis. Here fares may differentiate by time period and ticket type. The fares model includes different
approaches for the national rail and for the London Underground. For the national rail, fares are related to the distance travelled with the possibility of making local adjustments through geographical indicators. For the London Underground, fares are related to the existing fare zonal system.

7.2 MPL Katowice Airport demand model

Keywords: forecast demand model, regional

Reference: OBET, Poland

The liberalisation of transport leads to economic transformation and changes in market conditions. It is central to capture this adequately in a traffic demand forecast. In this example the demand volume operated by several Polish airports are investigated. A specific problem is the potential of the respective hinterlands (see Figure 7.3).

![Figure 7.3: Comparison of airport population potential with serviced quantity demand](image)

Especially in case of Katowice Pyrzowice Airport, it is obvious that the regional airport operating below the hinterland potential. This is due to a domination effect of the central airport, which has concentrated the service of the national carrier (PLL LOT assumed that, this airport will be a hub) in conditions before the liberalisation of the air transport market. That is why in case of demand modelling an elastic approach in this kind of market conditions is necessary.
The realisation of forecast purposes is a very important issue - determination of final demand in case of the general plan to enable the planning of airport development. This approach has been used at the international Airport Katowice in Pyrzowice.

**Objectives**
The general objective of the transport demand model was the evaluation of the development tendency in the range of passenger and cargo traffic as well as air operations until the year 2021. A short observation period did not permit to use only the extrapolation of trends in forecasts. Furthermore, traffic at the airport was changing as a result of taking over the traffic from Kraków-Balice airport during the period when the data about traffic volume were collected.

Simple methods of trends approximation (to establish the minimal forecasts) and elements of econometric modelling (to establish potential demand on the airport impact area) have been used in forecast of air traffic increase at MPL Katowice. A polynomial function of trends was the basis for the forecasts - it was a fourth degree polynomial.

Forecasts of the passenger number using air transport were made in two stages:

- Firstly, market potential of the air transport service on the area operated by MPL Katowice based on assumptions concerning increasing per capita gross domestic product (GDP) in Poland was assessed.
- Next, the forecast of passenger traffic operated by MPL Katowice was estimated.

**Methodology**
The forecasts of air traffic development in the area of MPL Katowice for the years 2001-2021 was based on a comparison of transport activity by inhabitants in Poland and some European countries. It was assumed that an increase of per capita gross domestic product (GDP) would increase air traffic demand (according to statistic regularity, which depends on the relationship of gross domestic product and transport volume) to a value equivalent to specific countries of Western Europe. Moreover, it was assumed that the liberalisation of the air market would cause an additional increase of air traffic – both in Poland and outside (15% increase until 2021 was assumed based on first results of the liberalisation that has been observed in Western Europe).

The main assumption of the demand model is that forecasts can be based on predicted increase in GDP together with the increase caused by the liberalisation of the air transport market.

The estimated transport activity has been converted into passenger number and the increase of transport activity has been spread out over the years 2004-2021 according to the following principle: until 2003 there is a 7,5% increase, then according to evenly divided accruals for years 2004-2021, which will cause the growth rate to annually decrease to 5% in 2018.

A fourth degree polynomial function was used to model demand. Only traffic to and from the operation area was considered in the calculations - potential transit traffic was not considered.
Potential demand volume has been estimated for two definitions of the MPL Katowice impact area:

- nearer hinterland inhabited by 4,250000 people (this corresponds approximately to the population within a 60 km radius from the airport),
- broader hinterland inhabited by 7,900000 people.

It has been assumed in the forecasts that the population in the area of the airport influence will not change.

**Data issues**
The demographic forecasts for the area of Śląskie Province (especially for the cities of Katowice Agglomeration) prepared by the Central Statistical Office was used in the forecast of air transport demand.

Predicted development of freight transport (cargo) and air operations has been based on the forecast of passenger traffic increase. The volume of cargo traffic and air operations have been extrapolated according to average forecast for passenger traffic.

**Applications**
The model has been used in the feasibility study „General plan of the Airport in Pyrzowice with the conception of the Airport area functional structure” (contracted by Marshals’ Office of Śląskie Province).

Based on the study, transformation of military area, handing over of this area to GTL and planning of airport growth have been started. The model has permitted to successful design of airport development.

Currently (in the sixth year since the forecasts were made) traffic in Katowice Pyrzowice airport is higher than predicted traffic. However, these forecasts are much closer to actual data for the year 2005 than is the case of calculations by British Aerospace and POLCONSULT based on a different demand model. A minor forecast mistake of the described model has been made in case of cargo traffic and air operations.

Forecasts mistakes were partly caused by a stronger influence connected with liberalisation than expected (the entry into the market of low-cost carriers from outside of current „players” group observed in European Union). This has caused more supply as a result of strong increase of emigration for economic reasons from Poland to Great Britain and Ireland.

It seems that the basis assumptions of the model (forecasts based on predicted increase in GDP and connected with it air traffic as well as taking into account the increase caused by market liberalisation) and estimations conducted for the airport base defined by isochrones may be used in a higher number of airports, which are subjected to transformation.

It is too early for general evaluation of model usefulness because of a probable decrease in growth, which in the years 2004-2006 has surpassed the most optimistic expectations and has
caused airports in Poland to belong to the most rapidly developing in the world. The model is dedicated to markets that experience extensive changes. In conditions of stable increase, econometric models based on precise forecasts of markets development are more appropriate. The demand model for airport services can be used in case of airports, which are in conditions of economy transformation under conditions with incomplete data and dynamic market changes.

7.3 PUTD, Public Urban Transport Demand model

Keywords: demand model, public urban transport, tickets sales

Reference: OBET, Poland

Identification of demand for public urban transport service is difficult because of problems with units used to describe demand and measurement. Demand „notice” is simple only in case of the use of specific distribution systems (based on electronic cards, which demand double „punching” by enter and before leave a vehicle). These systems are cheaper, but they are uncomfortable for passengers and they do not give precise information about the demand.

Evaluation of demand for the public urban transport services in the cities is conducted in these conditions with the use of traffic surveys or on the base of tickets sales figures. In the first case demand volume and passenger flows structure can be described. Demand estimated based on the ticket sale figures permit only to model transport volume, but it is easy to conduct and cheap. It is necessary to use some assumptions such that the base of demand estimations is a communication behaviour model, because tickets sale does not correspond directly to communication behaviour. It is necessary to make assumptions or conduct fragmentary statistical research in order to estimate number of journeys.

Objectives

Estimation of the demand for urban public transport demand, based on the ticket sales, was the main objective of the model. The range and strength of a downward trends in demand and the necessity of adjusting activities using marketing instruments and transport policy were addressed to the public transport operators.

Methodology

The following assumptions have been used on demand estimation in the in model:

- Single use (occasional) tickets sale corresponds to passenger number in a particular period without adjustment. Correspondence tariffs and so called bilateral tickets (two journeys of reduced tariff can be realised) – in this case the estimation of transport value needs a conversion of sale figures to the number of journeys. The following formula (on the basis of data about monthly tickets sale proportions in 2000) has been used in evaluation of passenger number (passenger journeys) with double punching tickets:

\[
\text{Passengers} = \frac{2 \cdot \text{sale}}{2 - 0.4625} = \frac{2 \cdot \text{sale}}{1.5375} = 1.30081 \cdot \text{sale} \approx 77649480.
\]
The volume of journeys based on commutation tickets (usually monthly) have been estimated on the base of a constant rate of journeys number with the particular type of ticket for which data are available – this rate has been adjusted to local conditions. Since the rate used by GUS does not suit to the condition (it was confirmed by the researches conducted in different cities in Poland) the following rates (estimated by expert methods) have been used in the model: 67.4 for a bus ticket and 57.9 for a bus-transport ticket.

The volume of journeys estimated on ticket sale figures has been corrected by the number of free transport and „fare dodger” – based on available statistical researches.

The estimated volume of passenger traffic determines demand volume for public urban transport services. A trend function has been derived. The future demand volume was forecasted by extrapolation of this trend function. The function can be presented in two variants of forecasts: minimum and maximum. This approach has been used in estimations of transport demand made in the model, where the trend function has either a form of pessimistic and optimistic scenario (see Figure 7.4).

Figure 7.4: Forecasts of urban public transport demand based on the ticket sale

Regarding internal substitution of ticket offers, the method of demand tendency estimations could not be replaced with ticket sale trends. This is the reason why a modelling approach that uses the observed communication behaviour (concerning especially journeys number of commutation tickets holders) is most suitable.

Data issues
The main data input comes from the special surveys on the number of journeys at specific routes as well as on the number monthly ticket sales.
Applications
The model has been applied by the public transport organisers in the cities of Śląskie Province; in the Municipal Transport Union of the Upper Silesian Industrial District in Katowice and Association of Commune Union in Jastrzebie. In both investigated Unions, the range and strength of the downward trends in demand and the necessity of adjusting activities with the use of marketing instruments have been described. The connection between motorisation rate and the rate estimated with a use of the demand model urban public transport has been also noticed (Figure 7.5 for Jastrzebie).

![Figure 7.5: Relations between motorisation and demand for public transport services](image)

A similar approach is also used in other cities – however there is a serious divergence in the range of rates used to estimate transport numbers of monthly tickets holders, passengers that have rights to free transport and „fare dodgers“. GUS uses the model that derives transport demand based on tickets sale– however conversion rates are stiff and separated from local specificity.

As shown, a model of demand based on ticket sale figures can be used in estimation of transport volume and can be used in transport forecasts. The main area of the model use is local transport policy.
8 Integration of model levels

8.1 Linking TRANS-TOOLS using GIS

Keywords: EU-level, integration, linking, GIS

Reference: Thomas Israelsen, Rapidis

The TRANS-TOOLS model is according to the knowledge of the author the largest existing transport model in terms of number of countries covered, population covered, geographical scale, as well as the complete coverage of both freight and passenger transport, including cars, trucks, trains, canal ships, sea ships, and air transport. The modelling complex links a regional economic model with demand models for freight and passenger transport. The freight model itself is especially ambitious, since it both models trade (as the model covers many countries), logistic chains (warehousing), and mode-chains (e.g., truck-rail-truck, or truck-ship-rail). The assignment models are also very complex, as they describe various trip purposes, equilibrate the routes concerning congestion, and describe multiple routes due to variation of preferences.

The TRANS-TOOLS model built on existing data, but ArcGIS has played a major role to merge different dataset, linking data, and especially for quality control. The workload pin-pointing bugs and afterward correcting them would have been overwhelming – and impossible -within the budget and time-frame – if a GIS approach had not been used. An additional challenge was that data originated from many different countries making the merge of data more complicated. As an innovation in transport modelling, ArcGIS has also been used to link all the models using the ArcGIS model builder and ArcGIS Geoprocessing framework. The core models are external .exe-files. The assignment models are more closely linked with ArcGIS, since they are a modified version of the Rapidis Traffic Analyst software (refer to www.rapidis.com). Using the ArcGIS Model Builder also helped the work process in building such a complex transport model over a relatively short time period.

Using the ArcGIS as a model interface made it much easier to illustrate, analyse and process data than in most transport models. Furthermore, the Model Builder interface can be used to run calculations as well as different scenarios. This potentially also enlarges the possible number of users. As an example, different offices and directorates of the European Commission use ArcGIS for other purposes than transport – or to analyse transport related data. They – as well as national Government and other potential users – may more easily learn TRANS-TOOLS if they already are ArcGIS users, than if a proprietary modelling software packages were used.

The TRANS-TOOLS model is now becoming the key decision support model concerning transport impact analyses conducted by the European Commission (European Union). Examples of analyses –and scenarios – are use to evaluate impacts of changes of taxation or road pricing, analyses of infrastructure improvements, analyses of future congestion in “do-nothing” scenarios, analyses of changes in GDP and population, etc.
Objectives
This example emphasises the use of ArcGIS in the TRANS-TOOLS Transport Model, TRANS-TOOLS, created by an international consortium for the European Commission (see Nielsen, 2006). The model describes passenger as well as freight transport in Europe with all medium and long distance modes (cars, vans, trucks, train, inland waterways, ships, and air transport).

ArcGIS was not only used for combining, improving and quality control of data, but by using the Geoprocessing Framework also as the backbone for the model complex itself. This includes a regional economic model, freight demand and trade models, a freight logistic model, passenger demand modelling, an airport choice sub-model, network assignment models for the different modes, and impact models for economics, safety, environment, etc.

Methodology
Figure 8.1 below provides an overview of the main model, as it is designed in the ArcGIS model builder (Muck-up). There is also a feedback mechanism in the model, that secures that the travel times from the network models influence transport demand and thereby the total transport volumes. Transport flows then influence the assignment and thereby congestion in the network. As ArcGIS 9.1 did not include possibilities for loops in Model Builder, this was done by scripts. It was later replaced in ArcGIS 9.2.

Demand models
The first model-step (not shown in the muck-up) is a Spatial Computable Generalised regional Equilibrium model (SCGE) – SCGEurope - that calculates the regional economic impacts due to changes in input data, including transport network characteristics. The model includes several economic sectors and goods categories. The spatial resolution is NUTS 2 (294 zones).

Secondly, a freight transport model calculates changes in 1) demand, 2) distribution of trade flows, 3) logistical chains, and 4) mode chains choices. These flows are then split into unimodal matrices used in the assignment procedures. The main model approaches are nested logit models and gravity models, although the trade model is a simultaneous model. The freight models works on a zonal structure with 1,286 zones.

The passenger model similarly calculates changes in 1) demand (total number of trips), 2) choice of destination, and 3) mode choice. The model design consists of nested logit models and gravity models. The utility functions are non-linear reflecting the wide distribution of trip lengths in a model that cover the entire Europe. The passenger model works on a structure with 1,270 zones.
Assignment models

The assignment models load the traffic onto the network, and calculate congestion levels. The road assignment models simultaneous loads passenger cars and trucks in a Multi-Class Mixed Probit Stochastic User Equilibrium Procedure. Different procedures are used to distinguish between peak hours and non-peak hours. Each user class has a separate utility function within which the coefficients follow distributions ("Mixed model") that reflect variation of preferences and Values of Time (VoT), which are assumed Logarithmic Normal distributed. The error term follows Gamma Distributions, which avoid the truncation problem of normal distributions, yet being able to model overlapping routes and approximate the results of a Probit model due to the central limit theorem.

The rail model assigns freight trains as well as passenger trains. Since no information was available on the exact schedule, a pure stochastic (Mixed Multi-class Probit) assignment procedure was used. Inland waterway freight transport is assigned onto the inland waterway network by a shortest path procedure that takes ship sizes (and size of the rivers/canals) into account.
Air model

The air model assigns the air journeys in the air network. In addition, it calculates the choice of feeder and access link, and choices of the airports that are used for the journey. The choice process is pretty complex for airports. More remote regions may have access to, e.g., a nearby local airport with few direct connections and high prices, other regional airports further away with direct connections to more locations, larger hubs even further away in a neighbour country with a more difficult land journey, and finally an even more distant national airport. The choice process is complicated due to the fact, that distance may not be proportional to travel times, but depending on, e.g., whether there are motorway or not, or whether there is a direct high-speed train or a chain of slow trains must be used. The travelling times for these are calculated by the car traffic assignment models and rail models respectively, and then imported into the air model. The choice of journeys between airports is then based on number of transfers, fare, and travelling time.

The overall air model is solved by a multi-modal multi-class traffic assignment model. The value of time differs between trip purposes (business traveller have the highest VoT, vacation the lowest), logarithmic normal distribution of these (e.g., to reflect income variation and variation of willingness to pay) and an error term (again approximating a probit model to describe overlapping routes). An example of a choice set is shown in Figure 8.2 below.

![Figure 8.2: Example of a joint choice set of airports and air-routes](image)

Impact models

Finally, a set of impact models calculates transport impacts such as time savings, costs, traffic accidents, pollution, energy use, etc. Most of these were implemented in the ArcGIS Geoprocessing framework.
Modes and trip purposes
As indicated above, the model describes all long and medium distance models. Each of these is split into different user classes, i.e., trip purposes. Freight transport is split into a number of goods categories. Available modes are trucks, rail (including rail ferries), inland waterways, and ships (sea-born transport). Passenger transport is split into three trip purposes: business, private, and vacation trips. Available modes are cars, rail (including rail ferries), and air.

Linking models
The resulting overall model system is more complex than the muck up in Figure 8.1 indicates. This is mainly because 1) the freight and passenger models include a number of sub-models, 2) the assignment models are different for each mode, and 3) the air model includes choices of airports and mode chains.

Furthermore, it is necessary with a number of data conversion steps (some of which were implemented directly by ArcGIS Geoprocessing framework). This includes disaggregation of flows from the economic model to the transport models’ and vice versa aggregation of transport costs and times for the economic model.

The economic model and trade model work on monetary values (e.g., Euro), while the remaining freight models work with freight volumes (Tonnes). These are then remodelled to truck units before the assignment. Similarly, passengers are remodelled to passenger car units before assignment. A further complication is that trips are split up into rush hours and non-rush hours before assignment, and that local road traffic is assigned onto the network.

The main philosophy when building this rather large model complex was NOT to link the models directly (Figure 8.4), but to build in intermediate data storage steps. This does not only allow for quality control of the results, but also makes it possible to replace and improve sub-models independently of the other models in future model updates. This is opposite many standard transport modelling software packages, where one is more or less locked to the same software for every steps.

Therefore, it was also decided to store all data and parameters in databases as well. The database thereby documents the settings for model use, and it is easily accessible through the Model Builder framework. It also makes it easier to run scenarios, to validate sub-models, to speed up calculation time, and to make quality control and validation easier.
Figure 8.3: Diagram of main model components
Implementaion
In general, the model is implemented with ArcGIS Model Builder as the front end interface. However, different sub-models were used, re-used, modified, or build to create the whole model system. Largely prior models were improved and linked to save resources. Therefore, the overall model consists of sub models that are linked to the overall framework by various approaches, i.e.,

- ArcGIS Geoprocessing tool
  - The data format is open, and besides the ESRI formats, it can use a wide array of other data sources, including MS Access, Oracle Database, SQL Server Database, Text files, etc.
  - Most import/export routines and processing of results were implemented in ArcGIS
- Models using the .NET component for use with C#, VB.NET or C++.NET
  - The assignment models
- COM components for use with C++ or VB 6 (or other COM-compliant languages) – some sub-modules
- Stand-alone executable programs (the SCGE model, freight model and passenger model)
  - Run by control file
  - Input and output as text-files (SCGE), databases (demand models)

As it is very slow dynamically to access to data in databases, each sub-model typically imports data and builds a more flexible internal pointer structure to speed up calculation time (refer to Figure ).
Data issues

The model consists of the following networks. The road network consists of 35,079 nodes, 47,373 links and 1,265 zonal connectors. The rail network consists of 18,851 nodes, 19,867 links and 1,269 zonal connectors. The inland waterway network consists of 747 nodes and 812 links, i.e., a very small network compared to the road and rail transportation networks. The air network consists of 522 airports, 8,507 links, and 7,962 zonal connectors.

The TRANS-TOOLS model was proposed to build exclusively on existing supposedly quality controlled traffic modelling data sets. When these were transferred into ArcGIS and visualised it soon became clear that massive problems existed concerning coherency, connectivity, and quality of network topology, as well as concerning the attribute data.

By use of existing ArcGIS tools, as well by use of some self-created tools linked together in the ArcGIS Geoprocessing Framework and Model Builder, it was possible to locate most problems automatically and also to fix most of the located problems automatically or semi-automatically. Still, the work effort was large (about a person-year) to quality control the model. However, the work effort would have been ten-fold without the ArcGIS-tools. Concerning the existing zonal connectors, some were found to have so low quality that new connectors were created from scratch by various set of overlay analyses, and afterwards manually quality controlled. Overall, this improved the quality of the network drastically.

Applications

Some clear innovations obtained from TRANS-TOOLS were:

- New set up of a demand/supply model;
- Intermodality for passenger/freight (as national and European transport policies promote intermodaliteit through different measures);
Inclusion of intercontinental flows (mainly for freight), as some models do not cover this segment;

Full coverage of Central and Eastern Europe (Accession Countries and the countries at the borders of the enlarged European Union);

Integration of the New Member States at a level similar to those of EU15 (former member countries);

Feedback infrastructure development economy (as the question of indirect effects in the economy and on network level is important, especially where investment has a substantial influence - notably for Accession Countries);

Logistics/freight chain explicitly included;

Coupling method with local traffic in order to address the effect of congestion on long-distance traffic;

The consortium provided access to all relevant experience concerning EU and national modelling;

A software approach was chosen that resulted in a software modelling tool on network level.

The homepage of the project (http://www.inro.tno.nl/transtools/Consortium.htm) describes the consortia and background in more detail.

8.2 Public Transport forecasts in the Euregio Meuse – Rhin

Keywords: operational, demand model, regional, public transport, cross border traffic, international transport model

Reference: Dr. Wim Korver, Goudappel Coffeng BV

The Euregio Meuse-Rhin (EMR) (see Figure 8.6) has the ambition to position and develop itself more as one region. It consists of the province of Limburg and Liege including the German-speaking community in Belgium, the region of Aachen in Germany, and the south part of the province of Limburg in the Netherlands. One of the key elements is a well functioning traffic and transport system. The ‘Euregional Public Transport Platform’ is meant to improve the cross-border bus and train connections for the Euregional transport, which also delivers a contribution to the transeuropean high-speed train. For strategic reasons EMR needed a quantitative build public transport forecast to calculate the impact of different variants. The results are needed to identify the current and future possibilities of the cross-border public transport in the region.

The study has been done in cooperation by Arcadis (Belgium), HHS (Germany) and Goudappel Coffeng (the Netherlands). The coordination was done by the Aachener Verkehsverbund (See also: http://www.avv.de).
Objective
The objective of this model is to support the ambition to stimulate the public transport in the EMR region.

Methodology
The base of the model is a classical four-step demand model and is based on the available regional model for the province of Limburg in the Netherlands. This model is in use for general assessment of transport projects in the province of Limburg.

The EMR model is a multi-modal system that describes the passenger trips for car, public transport, and bicycle. In this study the focus is in the public transport model. It estimates the number of passenger trips by public transport for an average day in the 2005 base year. Forecasts have been made for the year 2015.

The EMR model predicts demand for travel by five separated passenger purposes: work, business, shopping, school, and other. The EMR model is divided in 1,324 zones, where 970 zones are in the study area.

The trip distribution and mode choice are determined by a multi-modal gravity model. The skim matrices were build per purpose for the three defined modes. The skims are defined as generalized time based on the sum of travel time, travel cost, and other costs.

The travel costs for public transport are different for the defined purposes because it is assumed that someone who travels with purpose shopping buys a single ticket, while someone who is going to work normally uses a seasonal ticket (which is cheaper). For business travellers no travel costs are assumed because these travel costs are paid by the employer.

A special aspect when dealing with several countries is that a number of input values for the transport model could differ per country, whereas when dealing with one country most of the...
input values are the same all over the country. In this specific case the following approach was followed:

- To translate the travel cost into time the Value of Time is needed. No separation has been made between the Values of Time (VoT) in Belgium, Germany, and the Netherlands. The VoT’s in Table 8.1 have been used.
- The same price is used for fuel costs. There are differences in prices, but due to the fact that there are no barriers to go abroad to fill up your car, the perceived fuel prices are more or less the same for everybody;
- Public transport costs vary per country;
- Of course the developments of the number of inhabitants and employment per zone is based on national forecasts. In practice this means that substantial differences can occur in growth expectations between neighbouring regions.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Purpose</th>
<th>2005</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>Work</td>
<td>8.34</td>
<td>9.07</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>28.90</td>
<td>31.42</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>5.76</td>
<td>6.26</td>
</tr>
<tr>
<td></td>
<td>Freight</td>
<td>40.83</td>
<td>44.43</td>
</tr>
<tr>
<td>Train</td>
<td>Work</td>
<td>8.41</td>
<td>9.14</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>17.79</td>
<td>19.34</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>5.18</td>
<td>5.63</td>
</tr>
<tr>
<td>Bus/Tram</td>
<td>Work</td>
<td>7.83</td>
<td>8.51</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>13.64</td>
<td>14.83</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>4.95</td>
<td>5.38</td>
</tr>
</tbody>
</table>

Table 8.1: Value of Time for car and public transport (€ per hour)

A special aspect that of the model was the fact that the boarder-crossing trips by public transport are difficult to model, because:

- The flows are small;
- Crossing boarder behaviour is very different from national behaviour for several purposes, especially school;
- Little amount of data of current use of the public transport network was available.

This was solved by using a trip purpose specific factor to reflect the resistance for traffic crossing a boarder and secondly extra effort was put into collecting actual figures of the use of cross border public transport lines.

**Data issues**
The main data input comes from the national household-based travel survey in the Netherlands. Ideally, similar data should have been collected for Germany and Belgium, but this was not possible within the available budget.
Specific attention has been paid to the definition of the socio-economic data set. Because the data comes from three countries (from different model systems) the definition of variables was different. Therefore, adjustments were needed in the definitions to construct a common set for the total study area. In addition, the base year of the data from the three countries was different and not equal to the base year of the model, which is 2005. This has been solved by raising the sets per country to the level of 2005 based on national growth factors.

Figures and Tables

Table 8.2 presents the modal split for the southern regions of Limburg (the Netherlands), the province of Limburg in Belgium and the region of Aachen in Germany. It seems that there is a high PT market share between the Aachen-region from the Netherlands and Belgium and less interaction between the provinces of Limburg in the Netherlands and Belgium.

<table>
<thead>
<tr>
<th>Car</th>
<th>Limburg south (NL)</th>
<th>Limburg (B)</th>
<th>Aachen-region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limburg south (NL)</td>
<td>59%</td>
<td>85%</td>
<td>49%</td>
</tr>
<tr>
<td>Limburg (B)</td>
<td>87%</td>
<td>63%</td>
<td>63%</td>
</tr>
<tr>
<td>Aachen-region</td>
<td>43%</td>
<td>60%</td>
<td>50%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Public Transport</th>
<th>Limburg south (NL)</th>
<th>Limburg (B)</th>
<th>Aachen-region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limburg south (NL)</td>
<td>5%</td>
<td>11%</td>
<td>36%</td>
</tr>
<tr>
<td>Limburg (B)</td>
<td>10%</td>
<td>4%</td>
<td>37%</td>
</tr>
<tr>
<td>Aachen-region</td>
<td>44%</td>
<td>40%</td>
<td>5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bicycle</th>
<th>Limburg south (NL)</th>
<th>Limburg (B)</th>
<th>Aachen-region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limburg south (NL)</td>
<td>37%</td>
<td>4%</td>
<td>14%</td>
</tr>
<tr>
<td>Limburg (B)</td>
<td>4%</td>
<td>33%</td>
<td>0%</td>
</tr>
<tr>
<td>Aachen-region</td>
<td>13%</td>
<td>0%</td>
<td>45%</td>
</tr>
</tbody>
</table>

Table 8.2: Base year modal split in the EMR-region

However, considering the number of trips on an average working day it can be concluded that the cross-boarder transport has a very small share (see Table 8.3 and Table 8.4).

<table>
<thead>
<tr>
<th>All modes</th>
<th>Limburg south (NL)</th>
<th>Limburg (B)</th>
<th>Aachen-region</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limburg south (NL)</td>
<td>1480</td>
<td>15</td>
<td>13</td>
<td>1508</td>
</tr>
<tr>
<td>Limburg (B)</td>
<td>12</td>
<td>3778</td>
<td>3</td>
<td>3793</td>
</tr>
<tr>
<td>Aachen-region</td>
<td>14</td>
<td>4</td>
<td>2518</td>
<td>2536</td>
</tr>
<tr>
<td>Total</td>
<td>1505</td>
<td>3797</td>
<td>2535</td>
<td>7836</td>
</tr>
</tbody>
</table>

Table 8.3: Number of passenger trips (car, public transport and bicycle (* 1.000))
Table 8.4: Share of cross-boarder trips (* 1.000) in EMR-region

<table>
<thead>
<tr>
<th></th>
<th>Number of trips</th>
<th>Share of total number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands-Germany</td>
<td>27</td>
<td>0,3%</td>
</tr>
<tr>
<td>Germany-Belgium</td>
<td>8</td>
<td>0,1%</td>
</tr>
<tr>
<td>Belgium-Netherlands</td>
<td>26</td>
<td>0,3%</td>
</tr>
<tr>
<td>Total</td>
<td>61</td>
<td>0,8%</td>
</tr>
</tbody>
</table>

Applications

Economical development

By varying the expected economical growth, the most important social economic uncertainty can be shown. Therefore, two future expectations have been defined. The first is an economical trend scenario. This means that the economic growth will be moderate and be equal to the long-term average of the past twenty years. The second is a commonly used standard scenario in the Netherlands, and a situation with a higher economic growth than the trend scenario.

Public transport policy

The volume of public transport is obviously greatly dependent on the priorities of the policy. In this study, four possible policies of public transport have been considered:

1. Offensive: The supply creates its own demand. Public transport is leading in the transport policy in the region. This means it has high priority and substantially more money is reserved than currently. Practically this means doubling of frequencies of public transport lines and guarantee that each inhabitant of the EMR-region has good public transport connections. A good connection is defined by a bus stop or train station within 300 meters of the house and a minimal frequency of one line per 2 hours.

2. Optimal: Within the existing budget it is tried to let public transport have an important role in transport policy. This is shown by stimulating public transport actively, for instance developing P&R locations, low price increments, introduction of paying per kilometre for car (in Germany, Belgium and the Netherlands), integrated tariffs for crossing boarder trips et cetera.

3. Trend: The current public transport will be continued and no new policies will be developed. The costs for car and public transport stay the same as the present situation.

4. Negative: Lower costs for car and higher public transport tariffs, maintaining the present situation and no further reaching tariff integration.

Network scenarios

Three network scenarios have been defined. One of the scenarios is the status quo of the current public transport network and two other scenarios with a greater and/or better quality supply of the public transport.
Possible combinations

In theory 24 combinations (2 scenarios * 4 public transport policies * 3 network scenarios) were possible to calculate with the model system. Apart from the amount of work, it is not very useful to calculate all possible combinations. Therefore 8 combinations have been chosen and calculated with the model. These combinations are shown in Table 8.5.

<table>
<thead>
<tr>
<th>Description</th>
<th>Economic growth relative to trend</th>
<th>Public transport policy</th>
<th>Supply (network)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offensive, high growth scenario I</td>
<td>+</td>
<td>Offensive</td>
<td>I</td>
</tr>
<tr>
<td>Offensive, high growth scenario II</td>
<td>+</td>
<td>Offensive</td>
<td>II</td>
</tr>
<tr>
<td>Optimal, high growth scenario I</td>
<td>+</td>
<td>Optimal</td>
<td>I</td>
</tr>
<tr>
<td>Optimal, high growth scenario II</td>
<td>+</td>
<td>Optimal</td>
<td>II</td>
</tr>
<tr>
<td>Optimal, low growth scenario I</td>
<td>0</td>
<td>Optimal</td>
<td>I</td>
</tr>
<tr>
<td>Optimal, low growth scenario</td>
<td>0</td>
<td>Optimal</td>
<td>X</td>
</tr>
<tr>
<td>Optimal, low growth trend</td>
<td>0</td>
<td>Trend</td>
<td>X</td>
</tr>
<tr>
<td>Negative, low growth trend</td>
<td>0</td>
<td>Negative</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 8.5: Calculated model scenarios

The most important output for each variant that has been obtained is:

- Number of passengers for all public transport lines in the study area;
- Number of passengers for the boarder-crossing relations;
- Number of passenger boarding and alighting at each train station and bus stop in the study area;
- Compressed OD matrices by community.

Based on the outcomes of the variants an advice is written in which recommendations are made to which policy measures should have the highest priority. Separation has been made to policy measures for the short term and the long term and to effectiveness and feasibility.
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