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EXECUTIVE SUMMARY

The AIUTO (**A**ssessment of **I**nnovative **U**rban **T**ransport **O**ptions) project aimed to develop a system of models and methodologies for simulation, planning and evaluation, that merged the different aspects and contributions at a European level.
One of the first works of the AIUTO consortium was represented by a review and a classification of Transport Demand Management (TDM) measures (see chapter 2 of the Final Report): measures were identified, as belonging to the families of:

– innovative supply systems,
– regulation measures,
– pricing schemes, *and*
– other complementary measures.

TDM's had to be soft, reversible and flexible: thus, new infrastructure works were not taken into consideration. Furthermore, TDM's had to be proposed in the form of "packages" of measures of different families, in order to increase social acceptability and obtain synergetic effects in terms of transport results.
Main objectives of the suggested packages had to be reduction in car usage, increase in the modal share of low impact means of transport (namely public transport and innovative supply systems) and thus environmental and quality-of-life improvements.

The approach of the AIUTO project mainly had a model-oriented structure: models had to be used for assessing the effectiveness of the proposed packages. Some measures of effectiveness were proposed, arranged in a hierarchical structure. A long list of indicators was provided; a short list of the most important items was also suggested, as the minimum comparison level for all sites (chapter 3).

The model framework is described in chapter 4: a strong effort (due to the wide variety of possible approaches) was made in order to classify models into categories. The main categorisation of models is between *demand models* and *supply and assignment models*. These models simulate different possible choices made by travellers: the *trip frequency choice* (i.e. how many trips per day are to be done), the *departure time choice* (i.e. when a trip is going to be done), the *destination choice* (which will be the destination), the *mode choice* (which will be the mode of transport); the *route choice* (which path will be followed) and, only for cars, the *parking choice* (where the car will be parked). After a discussion about which different approaches should be used to implement models (trip-based, tour-based, activity time-based), a common framework for the AIUTO TDM's was agreed. The framework is composed of the *input data* (the structure of which will be described in the Annex), the *transportation models*, the *environmental models* (such as models able to estimate pollutant emissions, starting from a flow distribution on a network) and the final indicators of the modelling results, or *Measures of Effectiveness* (MOE's).

The AIUTO project involved six test sites (chapter 5), represented by cities of different sizes and features, spread over Europe, and ranging from 6.07 million inhabitants in the conurbation of Randstad (Netherlands) to 84,000 inhabitant of the tourist city of Como (Italy).

In the case of **Como**, both push and pull measures were tested, as well as a combination thereof, by means of a LOGIT switching model, estimating the changes from car to other modes. Push measures (park pricing and cordon pricing) obtained good results in terms of modal split (13.5% and 8.4% respectively) and environmental achievements (some 8% reduction in CO and NOx emissions). On the contrary, results of pull measures (increasing of public transport supply, Dial-a-Ride service), if applied alone, were extremely weak, giving rise to less than 1% changes. Mixed measures could somehow increase the above results.
For Como test site, a complete evaluation exercise, by means of a *Multi Criteria Analysis*

methodology, was also conducted. Results confirmed the low performance of pull measures, and indicated a better behaviour for Road pricing, as compared with Park pricing (road pricing involved a greater number of car drivers, so that similar revenues could be collected with lower individual charging). Both implementation costs and average generalised costs for users played an important role in this evaluation.

Also in **Salerno** both pull and push measures were simulated, including public transport enhancement (Park & Ride facilities), pricing measures (Park pricing) and regulation measures (Restricted access area). Scenarios were evaluated by means of a holding model, using specific sub-models for introducing the Parking choice and the Park & Ride choice. The scenario with a “package approach”, including all the above mentioned measures, obtained the best results with a car trip reduction exceeding 21%. The second best scenario appeared to be the Restricted access area, with a global 14.9% reduction in car trips and a local reduction of 80% in veh*km in the directly involved area.

The test site of **Randstad** performed simulations aimed at the medium term future. In addition to different types of demand management, a longer term oriented package including infrastructural provisions (new highways and lanes) was included in the analysis. Demand management measures included control measures (access control, traffic calming, HOV priority) and deterrent measures (pricing, parking management). Packages combined TDM’s of different groups and also aimed at assessing the effect of time-path (long-run/short-run variation). It was found that the path to the final policy effect is not smooth and immediate. In some cases, as had been predicted from the model elasticities, a final growth in demand can be preceded by an initial drop, or vice-versa.

In **York** a bus-lane along a penetration axis to the city was considered, including a queue-relocation mechanism for private cars. The scenarios evaluated the potential benefit to the bus, with or without a bus priority system or other complementary measures. Assessment was made with different modelling packages (STEER, PFE, SATURN, DRACULA), for comparison purposes. The main finding was that the modelled measures were not sufficiently strong enough, *by themselves*, to have a significant improvement on bus journey time. As regards models used, little difference was found in results from SATURN (Deterministic User Equilibrium) and PFE (Stochastic User Equilibrium). On the contrary, microsimulation was found to return better results (with respect to less detailed models of traffic) for pollution and safety indicators.

Also **Thessaloniki** included long terms measures in its scenarios, in the form of a new metro line and a tunnel bypass, together with different packages of pricing and regulatory measures. Simulations included a LOGIT mode choice model, based on stated preference data, and a SATURN assignment. The analysis concentrated on peak-hour: it was found that the aggregate mode choice model was not sensitive enough to investigate impacts from marginal changes in the level of service for private and public transport; a disaggregate model system would have been far more appropriate for testing the effects on the mode choice. The results also demonstrated that long term measures were able to create much more significant impacts on traffic, environment and energy consumption than the packages of ordinary TDM measures alone.

Finally, the **Geneva** test site included in its scenarios a *staggered and flexible activity time* for all commuters city-wide, together with other packages such as traffic calming or access control. Simulations were conducted with a *dynamic framework,* instead of the more used static approach.
The results showed that impacts on road usage for local policies, and in particular for traffic regulation or traffic calming, were mild. On the contrary, sensible effects were found for the interventions on the working time because of the sensible decrease in travel cost (decrease in the range of 0.3-0.6 ECU): the staggered hours (variability of the working time among companies) seemed to dominate the flexible ones (flexibility of the beginning time for the workers). Where combination of several TDM’s has been applied (e.g. staggered + flexible, staggered + flexible + fuel pricing), effects seemed to be superadditive.

An assessment of the models used for simulating each scenarios was a key issue in the AIUTO project (chapter 6).

As regards ***demand models***, comparison of switching vs. holding approaches has not shown an evident supremacy of one on the other. In general, switching models (e.g. as used in Como) have a generally easier analytical structure and are less *data intensive*. In the comparison between "all-day" and "peak-hour" approaches a non-negligible evidence has been shown that, for general cases, the all-day approach is recommended, as the effects of TDM measures are relevant – for example when a desired effect is to spread some of the peak-demand – and all-day indicators cannot be linearly or proportionally derived from peak-hour. When long terms measures were considered (as in Randstad), it seemed that transportation-land-use interaction models could be useful. It also appeared important to apply different systems of demand models to different groups of users: the disaggregate demand models used in the project have shown the relevance of demand segmentation. Finally, the AIUTO experiences have shown that a suitable and effective way in which different travel choices can be integrated into a consistent theoretical structure is using the nested LOGIT model.

As regards ***network assignment models***, traffic flows can be represented in a microscopic or macroscopic way. A microscopic model, where individual vehicles are separately modelled, is extremely computationally intensive, but has some advantages: one of the most important appeared to be represented by air pollution modelling (e.g. in York). Another main difference in assignment models is due to a *static* or *dynamic* approach. A dynamic model was found to be better able to capture "over-capacity" queuing. The impact of a replacement of the static model by a dynamic version in an existing transport modelling system was assessed in Randstad. The three dynamic models tested seemed to be capable of predicting the major congestion locations well, but they showed a greater similarity between themselves rather than between models and observations in individual links or static results. A conversion of a static to a dynamic assignment model has proved possible, though more work is needed on model refinements and validation.

Finally, the Annex proposes to organise data necessary for the simulation into a *data dictionary* structured following the rules suggested by the ALERT-STRADA project.

Contents

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AIUTO Partners	**Abbreviation**	**Country**
MIP - Politecnico di Milano	MIP	IT
Università degli Studi di Napoli "Federico II"	UNINA	IT
Centro Studi sui Sistemi di Trasporto S.p.A.	CSST	IT
SINTRA s.r.l.	SINTRA	IT
University of Newcastle	TORG	UK
University of Leeds	UNIVLEEDS	UK
University of York	UYORK	UK
EuroTRANS Consulting Ltd.	EUROTRANS	UK
Hague Consulting Groupe B.V.	HCG	NL
Facultes Universitaires Notre-Dame de la Paix	FUNDP	BE
TRIAS S.A.	TRIAS	GR
Ecole Polytechnique Federale de Lausanne – Institut des Transports et de Planification	ITEP-EPFL	CH

1. INTRODUCTION

Planners face greater challenges today than ever before in designing transport strategies for urban areas which provide for future travel needs in as a sustainable way as possible. No longer is it expected that the answer lies primarily with increasing the capacity of the road system. The current trend in urban transport policy shows instead an increasing attention to mobility management through Transport Demand Management (TDM) measures which are *soft* (i.e. without relevant infrastructure works), *reversible* (i.e. easy to reformulate at a later date to satisfy social acceptability) and *flexible* (i.e. responding as far as possible to user needs). International experience suggests that the social acceptability of TDM measures is strongly dependent on the manner of their implementation). These measures should, in combination, be a well-structured and flexible systems of incentives and checks, developed with the aim of transferring the social benefits (derived from the reduction of traffic congestion and pollution) into user benefits.

Within the Task 5.1.2/5 in the Urban Transport sub-programme of the EU 4th RTD&D Framework Transport Programme[1], the challenge for a study of soft, flexible and reversible measures was accepted by the AIUTO project (models and methodologies for the ***A***ssessment of ***I***nnovative ***U***rban ***T***ransport systems and policies ***O***ptions).

The main objectives of AIUTO were:

1. to develop a set of models and methodologies able to simulate and evaluate Transport Demand Management (TDM) measures, singly or combined into packages;
2. to assess the socio-economic and users' benefits of a range of TDM policies, based on structured and flexible packages of measures such as differential pricing, parking/access restrictions, car-pooling, park & ride, innovative transport supply services (line services, dial-a-ride, shared-time cars,...).

Secondary objectives were also present, as follows:

3. to conduct a European-wide assessment of existing transport models;
4. to improve transport models structure, adding more flexibility to transport supply models and promoting use of behavioural disaggregate demand models;
5. to improve models and algorithms for the evaluation of non conventional TDM measures and probable future policy options;
6. to stress the need for assessment models and evaluation methodologies for transport policy decision-making, with an emphasis on interactions among different actors.

AIUTO had an application-oriented approach as it intended to develop common guidelines and methodologies for TDM policies and innovative systems implementation integrating macroscopic and microscopic approaches at a European level, starting from a review of existing models and methodologies.
The project was based on six case studies, represented by different cities spread throughout Europe. They were: Como (IT), Salerno (IT), Randstad (NL), York (UK), Thessaloniki (GR) and Geneva (CH).

[1] Transport Management / Technique Tools - Predictive Modelling

2. TRANSPORT DEMAND MANAGEMENT (TDM) MEASURES

2.1 Classification

Within the AIUTO project, each test site has modelled a set of scenarios including various combinations of TDM measures. TDM measures can be considered as the *elemental policies* which allow a *transport strategy* to be implemented. Before the modelling phase, it appeared useful to the AIUTO Consortium to classify the TDM measures that were to be used in the modelling, and to conduct an international survey of all measures and innovative transport systems. The scheme of classification of TDM's is shown in the next table. The results of the survey form the subject of this chapter.

TDM's are classified into *Main Measures* and *Complementary Measures*. Main measures are in turn categorised into innovative supply systems, pricing measures and regulation measures. Each of them can be further classified on the basis of the particular kind of measure.
The classification aims to better identify each of the proposed scenarios and to allow for an easier comparison among scenarios, as all scenarios modelled in AIUTO will be described in chapter 5 as a combination of some of the TDM's reported in the following table.

TDM MAIN MEASURES			**COMPLEMENTARY MEASURES**
INNOVATIVE SUPPLY SYSTEMS	PRICING MEASURES	REGULATION MEASURES	
1. Park-and-Ride	1. Road pricing	1. Access control management measures	1. HOV priority measures
2. Car-pooling	2. Parking pricing	2. Parking management measures	2. Traffic light measures
3. Dial-a-ride	3. Public transport (PT) fare structure	3. Traffic calming	3. Variable Message Signals (VMS)
4. Card-operating cars		4. pedestrianisation & Cyclist measures	4. Ramp metering
		5. PT measures (traveller information systems, vehicle priority, integrated ticketing).	5. Enforcement of regulations (in particular, parking)
			6. Staggered activity times (in particular, school and working times)

Tab. 1 - Traffic Demand Management measures (TDM's) taxonomy.

2.2 Definition of the TDM Elementary Measures

2.2.1 Innovative Supply Systems

Introduction

Innovative supply systems are essentially new modes supplying services intermediate between private car and traditional transit for different demand segments (e.g. Park-&-Ride, dial-a-ride, card-operated-car, regulated car pooling). A definition of each of these systems, some of their advantages and disadvantages, and relevant case studies are given hereinafter.

Park-and-Ride

Definition

This measure extends the catchment of public transport into lower density areas, by enabling car drivers to drive to stations. The system can be used where parking lots can be located near interchange points, dedicated bus lanes, etc. Journey lengths and bus priorities also affect Park & Ride, as well as lower integrated prices for the parking and riding services.

The parking facility itself provides a low-cost way of extending the benefits of public transport, thus reducing congestion, environmental intrusion and accidents in inner urban areas. It does not, however, offer significant improvements in accessibility and equity, since, mostly, only car users can use the facility.

Park & Ride has mainly been used to deal with trips towards the central congested areas. In addition, jointly with land-use developments such as large commercial centres, it may reduce the need for optional trips and chains. The system can be enhanced if it is accompanied by an integrated fare structure with public transport. Also, “pre” and “on” trip information of available public transport routes, time tables, automatic ticketing facilities and good connections at the parking terminals with public transport facilities would improve Park & Ride systems.

Applications

Park & Ride has been used successfully in smaller cities such as Oxford and York in conjunction with dedicated bus services (Bixby, 1988; McPherson, 1992).

Some doubt has been cast, recently, on the true benefits of Park-and-Ride; a survey has suggested that it may in practice generate longer journeys by rural residents, and hence increase car use (Pickett 1995). However, surveys carried out in York in 1993 showed that 11% of respondents would not have come to York by car were Park & Ride unavailable, while 61% of all respondents would still have come by car and parked in York city centre (York District Council, 1995). There is also the possibility of the diversion of trips from public transport to Park-&-Ride.

Car-Pooling

Definition

Car-pooling offers a means of reducing car traffic while retaining many of the advantages of private car travel. It is a system which involves several users sharing one private vehicle to make the same or similar trips. There is a clear distinction between car-pooling and ride-sharing. Ride-sharing schemes can be used by non-drivers who may arrange to be picked up by drivers. On the contrary, car-poolers are individuals who would otherwise have driven: in this case the scheme would be explicitly designed to reduce the number of cars being used.

Applications

In order to guarantee continual and systematic operation, car-pooling requires an operator and incentives to participants. Indeed, the division of costs is usually not a sufficient incentive to spread

and maintain this form of transport over time (SAVE, 1996). Experience suggests that the numbers sharing voluntarily, even with incentives, are unlikely to exceed 5% of car users, and that their passengers are as likely to transfer from bus use as from other cars (Bonsall et al, 1981). Models of the effects of car-pooling on the network have been evaluated (HCG, 1993).
Some complementary measures to enhance this system could be High Occupancy Vehicle (HOV) lanes and parking places, reduction from road-use pricing and availability of control centres to organise matching travellers and financial aspects.

Dial-a-Ride

Definition

Demand responsive transit (DRT), when introduced into the public transportation arena in the early 1970's, represented the first major transit service innovation in many decades. Dial-a-Ride, as DRT was then usually referred to, was designed as a transit system that accessed the user and delivered the individual to the desired destination. Conceived as the first truly "smart" public transit technology, DRT was also the first transit innovation premised explicitly on computer technology. This system is an on-demand transport service, in which by means of a centralised booking system a group of vehicles without fixed routes or timetables can serve the users.
Bookings are made (by telephone) to a control centre, indicating pick-up and delivery points, and the desired "time window" in which the journey is to be made. The nearest vehicle, or that which can best satisfy the request in terms of the established quality standards, services the request. The heart of the system is the computer control, in particular, the means of best assigning a vehicle to a new request whilst minimising the cost to other passengers.

Applications

Recent technological developments offer the promise that DRT may be able to return to its "smart" technological roots to restore its potential as a service for the general public - although at a much superior level of performance and cost-effectiveness. These developments include the advent of low cost, high performance computer hardware, generic relational database systems, moderately priced scheduling and dispatching software, mobile computers, off-the-shelf automatic vehicle location technology, and electronic mapping software (Teal, 1994).
Effectively, the problem is a matter of guaranteeing a level of service appropriate to the fare and exploiting the residual time for new requests for service. In methodological terms, it is a problem of routing and scheduling (SAVE, 1996). Bus priority measures on existing bus routes and/or HOV lanes can support the system. Also, this system could be complemented by "pre" and "on" vehicle information of the available public transport routes, time tables and so on.

Card-Operating Cars

Definition

This system involves the provision, in a network of centrally located parks, of (preferably electrically-propelled) small cars which can be hired by the use of a magnetic card. The card holds details of the driver and allows direct debiting of the hire fee. The car is returned to any of the available parks present in the network. From a methodological point of view there is (as with Park & Ride) the problem of park location, as well as possible queuing (SAVE, 1996).

2.2.2 Pricing Measures

Introduction

Pricing measures represent powerful demand management tools for transport demand management. They constitute disincentives for road usage and, if accompanied with other appropriate incentives to use other modes of transport, will produce significant effects on the pattern of demand. They can also reflect the marginal, social, pollution and environment costs of congestion.

The internalisation of the external (or marginal) costs, following the “polluter pays” principle, has been proposed by many (see May et al, 1994; Smith et al, 1994a; Smith et al, 1994b, and May, 1986). In the Green Paper, presented by the European Commission-DGVII and already available when the project started, a reference has been made to “fair and efficient” pricing. The objective is to ensure that prices reflect all costs and benefits so that businesses and citizens base their decisions on the right price signals. Similar objectives are present in the more recent white paper on Fair Payment for Infrastructure Use, issued by the Commission after the end of the AIUTO project.

Road-use pricing measures have been proposed in a number of forms. In particular, *road pricing* (in the forms of cordon-, distance-, time- and congestion-based pricing, detailed in the following) can be used to reach the following objectives:

- significantly reduce car use in the charged area;
- hence, reduce environmental impact and accidents;
- make public transport receive benefit from the reduced congestion;
- increase accessibility (although this will be counter-balanced by increased money costs for private travel);
- generate substantial revenue, which can potentially be used to finance other elements of a transport strategy.

Nevertheless, it is important to note that the last item is in general contradictory with respect to the previous ones: the more the shift towards public transport is limited, the higher the revenues that can be collected. The strength of the charging thus plays a fundamental role in orienting the pricing towards one or the other objective. A lower charging can lead to a small car reduction and corresponding higher total revenues. A higher charging can cut most of the demand by car, therefore reducing number of payers.

The selection of the *main* objective (reduce car use vs. collect revenues) should therefore be done before any implementation of a pricing scheme.

Cordon Pricing

Definition

Toll cordons represent the most conventional form of road user charging. A charge is levied at the boundary of a specific area, defined by a single or series of boundaries. The charge incurred for a trip is directly related to the number of boundary crossings. Charges may be varied from boundary to boundary, by time of day, by direction or vehicle type/user class. They can also be varied, within a give boundary, for example depending on congestion, in order to encourage a real-time change in route or in the time of the trip.

Applications

Toll cordon systems operate in three Norwegian cities; Bergen, Oslo and Trondheim (see for example Tretvik, 1992, and Meland and Polak, 1993). This schemes were designed with the main objective of raising revenue rather than controlling traffic levels. A study of the toll ring in Oslo (Larsen, 1988), for example, confirmed that the effects of the toll ring on the total car traffic was limited to a traffic reduction amount between 5 and 10% (principally outside peak hours), and that there was no increase in car occupancy, or in ticket sales for public transport.

More recently, cordon pricing has been used as a demand management tool (see Larsen, 1989).

In the Netherlands, the Dutch Ministry of Transport has been studying a multiple-cordon-based road pricing scheme since 1992 with the objective of regulating traffic flow by use of a time- and location-dependent pricing mechanism (see Stoelhorst and Zandbergen, 1990).

During August 1991, identical public opinion exercises relating to road-pricing were conducted in Bergen, Oslo and Trondheim in connection with the PAMELA project (Thorpe and Hills, 1991, and Skjeseth and Odeck, 1993). The results show that the respondents in Trondheim to a lesser extent than those in the two other cities felt congestion was a major problem and that tolls should be raised as and when congestion gets worse. On the other hand, they were less negative than the respondents in Bergen and Oslo to the idea of increased charges during the morning peak-period above the uniform rate for the rest of the day (see also Tretvik, 1993).

Time-Based Road Pricing

Definition

This is based upon variable charging being levied based upon the time spent in the specified area. Charge rates may be varied by time of day, vehicle user class and across a series of different zones. One applicable technology consists of microwave roadside beacons to supply charge information to in-vehicle units (IVUs), perhaps attached to the windscreen of the cars, where the transaction takes place. The driver could pay for travel using a smart card, based upon the time spent travelling in a specified area. This form of cashless payment could conveniently replace parking meters and the need to carry (and collect) small change.

Distance-Based Road Pricing

Definition

Distance-based charging is essentially similar in terms of technology requirements to time-based systems, with a variable charge being levied on the distance travelled in a specified area. The main distinction is that distance charges are unaffected by congestion levels so that targeting specific times and locations can only be achieved by varying the charge levels by time of day and across a series of zones. The main advantages of distance charges are practical, relating to the easier way to compute the charging and to the predictability of journey costs, which removes concerns about the effect of charging on driver behaviour.

Applications

Systems which charge continuously in a defined area, based on time taken or distance travelled have been proposed. In the Netherlands, The HCG has conducted extensive studies of the impacts of road pricing (in many forms) since 1986 up to now (see, for example, Heitakamp and Gerritse, 1990).

Congestion-Based Road Pricing

Definition

The concept of congestion metering involves relating road user charges directly to the prevailing level of congestion on the road network. Its supporters consider it to be fairer than toll cordons and time-based charging, because a charge is only levied when congestion occurs. As with time-based charging, the technology of microwave beacons and an IVU (in-vehicle unit) is required.

Applications

Singapore in 1975 was the first city to adopt a form of congestion pricing based on area licensing. This was complemented by an increased parking fee in the central area, and a park-and-ride scheme to provide a suitable alternative for private motorists (Holland and Watson, 1978, and Hau, 1990).

The congestion metering system demonstrated in Cambridge in 1993/94 involved the recording of the time taken and distance travelled for each vehicle by in-vehicle technology. Only when a specified time/distance threshold is exceeded does the IVU deduct a charge (Oldridge, 1990). The most commonly suggested time/distance threshold is three minutes to travel half a kilometre.

The system has generally been conceived to operate within a single cordon, around the perimeter of the urban area, with congestion being charged at a single rate throughout. Thus, when a vehicle enters the congestion metering area, a charge may not be levied until at least half a kilometre has been travelled. On passing a beacon on the perimeter cordon the congestion metering technology would be activated and would record travel times at ten metre intervals. Once a full half kilometre has been travelled, the IVU would review the data to test whether the threshold has been broken and would continue to do this at each subsequent ten metre measuring point. If the threshold has been exceeded, a fixed charge would be deducted and the recording process would be reset so that another half kilometre must be travelled before a further charge may be levied.

Opponents of congestion metering have expressed concerns that charges incurred may be unreliable and lead to erratic travel decisions. The inability of users to predict charges accurately prior to travelling would also be perceived to have equity disbenefits (Milne, 1993). Congestion-and time-based charges perform well, producing increases in speeds in the charged area at all charge levels tested. Greater increases in speed within the charged area are offset by larger reductions to outer orbital speed when compared with time-based charges. The results were as follows:

- all systems increase distance travelled by users while reducing travel times; and
- charges, which reduce trips by 10%, reduce total distance travelled by 4%.

Parking Pricing Measures

Definition

Parking pricing measures provide one of the most widely used forms of parking control. Uniquely among parking control measures, they enable demand to be kept below the supply of parking spaces, thus reducing time spent searching. Different pricing strategies are available and include: flat, time proportional, maximum stay, and combinations of them. Elasticity with respect to parking charges vary depending upon availability of alternatives, but figures in the range -0.2 to -0.4 have been quoted. The general definition of price elasticities is the percentage change in quantity demanded by an individual in response to a one percent change in price. The wider impacts depend on the alternative used by the car driver; parking on the fringes of the controlled area or in private parking spaces will inevitably have less impact on efficiency and the environment than switching to public transport.

Public Transport Pricing Measures

Definition

Fare pricing can be adjusted on all public transport services, and will have a direct effect on patronage and on car use. The measures includes adjusting and differentiating fares according to users (workers vs. students, commuters vs. non-systematic trips, elderly people, ...), areas (zone tariffs), means of transport (including intermodal ticketing), time band of the trip (workdays, holidays, evenings, ...).

Evidence suggests a fare elasticity of around -0.3 for buses and slightly higher for rail. Cross-elasticity for car use are around +0.05. However, fare changes apply throughout an urban area, and may thus have a greater absolute impact on car use. Fare reductions can, therefore, contribute to efficiency and environmental objectives, as well as improving accessibility for public transport users and equity. On the other hand, there is also some evidence that low fares may encourage longer distance travel.

2.2.3 Regulation Measures

Introduction

These are non-price measures aiming at providing disincentives to car usage and providing incentives for the use of other transport modes (including walk).

Access Control Management Measures

Definition

These sets of measures concern the implementation of a common set of rules which establish a selective restriction on vehicle access at a set of points on the road network according to characteristics associated with individual vehicles and their usage, such as time of day/week, vehicle type, user type (resident, paying, visitor, etc.) duration of stay, etc. Automatic vehicle identification technology offers the potential for overcoming the principle drawbacks concerning the application of access control measures over a sufficiently large area to have an impact upon trip patterns (high enforcement labour costs, delays at the control points, unreliability and equity involved in issues associated with manual validation, etc.).

Applications

An access control system mainly consists of a control centre and roadside control equipment which interacts with the user validation equipment. This system has been adopted in the city of Barcelona, where the main objective for the local authority is to extend the pedestrianisation in the historic city centre (see Hays et al, 1994). Similar environmental benefits (associated with reductions in vehicle flows) are expected from the automation of the existing manually-enforced restriction of vehicle access to the city centre in Bologna. Complementary measures are traffic lights, information systems and enforcement.

Parking Management Measures

Definition

Potentially these provide a more effective way of controlling car use. Control can be achieved by reducing the supply of spaces, restricting the duration of parking or the opening hours, or regulating their use through permits or charging. The performance will depend very much on the way in which controls are applied. Simply reducing space is likely to increase the amount of time spent searching for parking space, which may have adverse impacts on congestion. On the other hand, parking on the fringes of the controlled area, or in private parking spaces, will inevitably have less impact on efficiency and the environment than switching to public transport.

Applications

Static parking management systems (parking routes) are operational in several cities. In the city of Hague for example, a dynamic system is available using variable message signs to provide holiday drivers to the beach with information about public transport and parking their car at the border of the city. Recently, many towns and municipalities are implementing parking policies to regulate car use. For example, the Dutch Railways contracted HCG to model the effects of parking policies at the origin and destination on the mode choice for commuting and leisure trips. The study resulted in a model system forecasting the effects of parking policies on the mode choice. Parking management can contribute to demand management in combination with public transport information.

Traffic Calming

Definition

Traffic calming measures are designed to reduce the adverse environmental and safety impacts of car (and commercial vehicles) use. They have traditionally focused on residential streets, and have involved two types of approach: *segregation*, in which extraneous traffic is removed; and *integration*, in which traffic is permitted, but encouraged to respect the environment.

Segregation can be achieved by the use of one-way streets, closures and banned turns, which makes through traffic difficult and hence diverting it to surrounding streets. The extra traffic on surrounding streets can add to congestion and environmental problems as well as loss of accessibility there, and so this trade-off needs to be carefully considered at the design stage.

Applications

By making routes through residential areas slower, traffic calming also induce re-routing, and hence a reduction in environmental impacts (Sumner and Baguley, 1979). Such benefits may be reduced by increases in congestion and environmental impact on the diversion route. The general opinion of the public are usually mixed, although generally favourable (see, for example, Windle and Mackie, 1992). The key issue currently is that of balancing the cost of provision against the effectiveness and visual quality (Hass-Klau et al, 1992).

Complementary measures include low speed limits, speed humps, pinch points, resurfacing and planting, all designed to encourage drivers to drive more slowly and cautiously. Experience in the UK generally deals with speed humps. Traffic calming is widespread in German speaking areas, and especially in Austria, where 30km/h-zones represent the standard regulation for local streets in residential areas. It is also clear that traffic calming can achieve significant reduction in speed and accidents.

Pedestrianisation and Cyclist Measures

Definition

Such measures provide a dramatic improvement in the environment for pedestrians and cyclists, and have proved very successful in enhancing trade in many town and city centres. They include cycle lanes and priorities, cycle parking and the provision of pedestrian crossing facilities. These measures present some accessibility problems for cars and bus users and for goods delivery services, as cyclist almost inevitably reduce road capacity.

Applications

A Cycling Strategy has been adopted in the city of York (UK), in 1988 to improve road safety and promote the use of the bike. Safe cycle routes have been designed. Full signing, signalised cycle crossing, approach lanes, advanced stop lines and cycling parking have been installed at key locations in the city (York District Council, 1995).

Public Transport Measures

Definition

Public Transport priority measures enable buses to bypass congested traffic and hence to experience reduced and more reliable journey times. The most common measures are with-flow bus lanes; others include bus gates or bus-only sections, exemption from banned turns, selective detection at signals, and UTC timings weighted to favour buses.

Applications

Conventionally bus priorities in the UK are designed to keep loss of capacity to other traffic to a minimum. With-flow bus lanes achieve this by stopping short of the junction stop line. Provided that this has been done, efficiency is usually improved; travel time savings to buses can exceed 25% while there are few losses to other traffic. In a development of bus priorities in London (the Red Routes) in which bus lanes are combined with intensive, well enforced, parking restrictions, travel time savings on the pilot Red Route have been dramatic, while the evidence of effects on frontage access and trade at the junction is mixed (Wood and Smith, 1992). Unfortunately there is little evidence from the literature that bus travel time savings are sufficient to induce a switch from car to bus travel.

Moreover, there is a growing recognition throughout the members of states of the European Union of the need for good-quality public transport to both provide an alternative to private transport in congested urban areas and to reduce the environmental impact of cars. For example, the work of Area Group 7 within the DRIVE Programme has concentrated on the major technical and social issues influencing the development and successful implementation of ATT application of public transport Management and Information systems (see Finn and Holmes, 1994).

The major European projects in this area are/were: EUROBUS, GAUDI, LLAMD, PHOEBUS, PROMPT, QUARTET, INCOME, MUSIC and SCOPE. The EUROBUS project is concerned with the development of a reference data model for public transport applications and the development of computer-aided tools for passenger information services. The GAUDI project involves five cities (Barcelona, Bologna, Dublin, Marseilles and Trondheim) where multi-service urban debiting systems are being demonstrated as ways of implementing policies which can orient usage from private towards public transport. In the LLAMD project, the main public transport applications were in Lyon and Munich and concerned both traveller information and public transport priority. The PHOEBUS project has concentrated upon development, implementation, and evaluation of pilot projects involving both simple and complex Vehicle Scheduling and Control Systems, with passenger information systems.

The primary objective of the PROMPT project is the development and demonstration of techniques for giving active priority to buses and trams in fixed and real-time adaptive urban traffic control (UTC) systems. Finally, in the QUARTET project the cities of Athens, Birmingham, Stuttgart and Torino are co-operating in the development of ATT applications for traffic control and information strategies in major urban areas.

2.2.4 Complementary Management Measures

Introduction

These are measures usually adopted to increase efficiency of modal networks, and can be added to support elemental TDM measures; for instance reserved bus lanes for P&R schemes. A large number of this type of measure have been proposed, but in the following only those usually adopted in conjunction with other TDM measures will be described.

High Occupancy Vehicle Measures

Definition

These measures extend the use of with-flow bus lanes to other vehicles which make more effective use of scarce road space. They can include car shares, taxis and commercial vehicles.

Applications

Experience includes for example Amsterdam, where HOV and HGV lanes have been studied extensively and various projects have been completed including a project of recent research into dynamic traffic management in the Netherlands. Amongst these are HOV lanes between the Hague and Gouda on the A1 motorway, between Amsterdam and Huizen. Another HOV experiment is running on a 22 km long corridor from North West surroundings to Madrid, in the form of a “reversible” 2-lane carriageway, inbound in the morning and outbound in the evening. The measure started in 1994 with a cut limit of 2+; at present 35% of vehicles use the HOV in the morning peak hour (85% with 2 occupants, 15% with 3+ occupants). Within EU project TransPrice, modelling was conducted in order to test the willingness to pay of solo-drivers to use the HOV lane: the willingness to pay was found to be quite low (no more than 0.25 ECU for the whole corridor). Further experience regard the city of Leeds, UK, and various interurban roads in California.

Variable Message Signs (VMS)

Definition

Including variable direction sign (VDS), these provide drivers with up-to-the-minute information regarding traffic conditions on the strategic road network. This information relates to congested conditions, queue lengths, incidents on the motorway, parking sites and parking guidance information. The VMS provide collective route guidance at decision points in a network to enable drivers to be diverted away from known, but unpredictable, congestion. They are very location-specific in their application, and hence in their benefits. Potential benefits are primarily in terms of efficiency as drivers are unlikely to be willing to divert in significant numbers to avoid environmental and safety problems.

Applications

In the case study project CITRAC/FEDICS (1996) to provide an integrated driver information and control system throughout central Scotland, it was concluded that VMS were successful, in terms of economic benefits and user acceptance.

In a recent research into dynamic traffic management in the Netherlands, the RIA (Route Information Amsterdam) which is reported to be the first application of VMS in the Netherlands, has been assessed and reported (HCG, 1996). It was concluded that RIA-sign technically performs well, is positively valued by car drivers and is effective at the level of the individual car driver. The effectiveness of the sign was demonstrated both for the short- and the long-term. There are indications of the positive effects of this measure, in terms of the duration and severity of the queues, changing travel behaviour (route switch) and also in terms of reduction in travel times. In a European-funded DRIVE II project (PRIMAVERA), which is concerned with the development and evaluation of strategies which integrate Advanced Transport Telematics (ATT) components for queue management, public transport priority and traffic calming on urban arterial roads (Fox et al, 1995), the effects of VMS and speed cameras in one of the trial sites (Leeds) is reported. Speed profile data collected around the VMS have shown its effectiveness. The number of vehicles exceeding the speed limit has dropped from 18% to 4%. According to another report by the TRL (Finch et al, 1994), this is likely to result in a 20% reduction in accident rates at that site.

Ramp Metering

Definition

Frequently a congestion problem arises when too many vehicles enter a main road though its junctions. In such cases, the so called ramp metering can be useful, i.e. a regulation system that artificially reduces the flow of vehicles on secondary routes, approaching to a main junction, generally by means of a traffic light with short green phase.

Applications

Ramp metering is a is well known in the United States of America, has been applied in the Netherlands and has been piloted in the UK and France (Recent Research into Dynamic Traffic Management in the Netherlands, 1996). The strategy chosen in the Netherlands is similar to the American strategy: a short cycle time such that only one car per green is allowed. To avoid delay to public transport, there is a bus-lane in which the bus can bypass the queue in front of the signal. There are currently two examples of ramp-metering projects in the Netherlands. One system is in operation at the Coentunnel to the west of Amsterdam (a motorway with frequent recurrence of congestion resulting from a bottleneck). The other system is on the A13 motorway near the city of Delft. Both systems are now in their second year of operation and the measured results in terms of impact on traffic operations are very positive.

In the experiments in Delft, a higher capacity (up to 5%) was observed and queue lengths reduced in both good and bad weather conditions. However, no gain in capacity was reported in the Amsterdam system. The acceptance of the system proved to be less satisfactory for the Delft system, while the Amsterdam system scores much better in this respect. The impact of a ramp metering strategy on an urban corridor has been reported (Salem and Papageorgiou, 1995).

2.3 The package Approach

The problems associated with the movement of people and goods in urban areas means that there is an increasing need to combine systems and measures which are designed to facilitate the management of public and private vehicles. A number of European studies and projects have considered opportunities for integration (see for example V1008, 1989; Jones, 1991; Oda, 1990; Saint-Laurent et al, 1994 and SAVE, 1996).
No one TDM measure is likely to provide a solution to the urban transport problems on its own. A package of TDM measures (and other complementary measures), however, is more likely to contribute towards the management and control of transport demand. “A package is a set of transport works and measures designed to work together to achieve certain objectives” (DoT, 1994). “...Defining urban transport policy in terms of a complementary package of measures that both restrains car use and provides acceptable alternatives has two main advantages. First, it is more likely to “work” and second, it is more likely to be accepted by the man in the street...” (Jones, 1991). In 1993, the U.K. Department of Transport (DoT) introduced the package approach as a basis for local authorities to develop ‘packages bids’ for government funding for transport projects.
In this project, a “TDM package” can be defined as concerted programmes of incentives and disincentives of TDM measures and complementary measures, the *objectives* of which can be as follow:

- to effectively address the different, sometimes conflicting objectives of urban transport policies;
- to emphasise synergetic effects of each single measures in order to reduce car use and congestion;
- to offer a wider set of alternatives to the user (including innovative transport systems);
- to obtain possibly greater results in terms of modal changes towards modes different from private car;
- to reduce opposition to pricing (or general pushing) measures, by accompanying them with pull or complementary measures;
- to increase public acceptability of the transport policy.

Each main measure can be accompanied by one or more complementary measures, selected among those that are *compatible* with the main measure (both technically and as regards objectives), and are supposed to improve the performance of the main measure towards the above stated objectives.
Table 2 below presents some *examples* of compatible complementary measures for each main TDM. These sets of measures should represent the basic tool-box for planners and decision-makers to provide more effective and efficient TDM packages. Modelling of the packages (as presented in each test site in chapter 5), in combination with a proper evaluation method, can be used to manage possibly contradictory issues.

	Main measures												
	Supply				***Pricing***					***Regulation***			
Complementary measure	Park & Ride	Car-pooling	Dial-a-ride	Card-operated-cars	Road pricing	Cordon-based priorities	Tolling	Parking pricing	PT fare structure	Access control	Parking management	Traffic calming	Pedestrianisation
Electronics													
Automated operation										X			
Automatic payment facilities					X	X	X						
Automatic ticketing facilities	X												
Computer hardware systems			X										
Flexible common payment media									X				
Vehicle locator device			X										
Information													
Database system			X										
Informative measures											X		
On-demand help lines				X									
Pre and "on" trip information on available public transport	X		X							X			
Pre and "on" trip information on pricing structure					X	X	X		X				
User Information				X									
Infrastructure													
Cyclist measures												X	X
Good connections of parking terminals with PT facilities	X												
Integrated PT facilities (interchanges, etc.)									X				X
Integration with PT network (parking location near interchanges)			X	X									
Park & Ride										X	X		X
Regulation													
Bus priority measures			X		X	X	X			X			
Control centres		X		X									
Enforcement					X	X	X	X		X	X		
High occupancy vehicles access to parking places		X											
High occupancy vehicles lanes		X	X										
Integration with P&R schemes				X									
Pedestrianisation	X												
Priority parking for residences								X					
PT priorities											X		
Structured access priority										X			
Traffic light measures	X	X	X	X						X	X	X	
Tariffs													
Discount (or exemption) of parking charge for car poolers/sharers								X					
Integrated fare structure between public transport and P&R	X												
Integrated fare structures between PT modes (and different companies)									X				
Pre-booking charging structure								X					
Public transport fare structure					X	X	X						
Reduced (or exemption from) road pricing		X											
Variable pricing structure based on level of congestion/pollution, ...						X	X						
Variable pricing structure based on time of the day, duration of stay, ...								X					

Tab. 2 - Examples of complementary measures compatible with the AIUTO main measures

3. MEASURES OF EFFECTIVENESS (MOE'S)

This section deals with the TDM's effects. Remembering the concept of TDM package, set forth in chapter 2, the following set of definitions are now introduced:

- the **packages** *(*or **scenarios***,* or **alternatives***)*, as a set of actions which completely define the possible choices, with sufficient details (the alternative must be clearly defined with respect to *location*, *regulation-enhancements* features and *level of pricing*, if any);
- the **indicators***,* which are symbols or numbers representing estimates (quantitative or qualitative) of the set of the effects; each indicator is related to a *reference period,* which is the time range in which an effect is estimated by an indicator (it could be the peak hour, the non-peak hour, the average weekday and so on);
- the **Measures Of Effectiveness** *(MOEs)*, which are the difference between the value of the indicator related to a given alternative and the "do nothing" situation;
- the **time horizon***,* which is the time range in which the effects of the alternatives are simulated (it can be a long term or a short-medium term, with different effects);
- the **criterion***,* which is a viewpoint from which it is possible to judge generalised benefits (or generalised costs) related to the different alternatives; it can be structured in more than one indicators, that allow the criterion itself to be described; the criterion is often related to a goal (for example, to decrease congestion);
- the **evaluation matrix**, which is a matrix whose m rows and n columns represent respectively m indicators and n scenarios: the internal element X_{ij} is thus the value assumed by indicator i if alternative j is chosen, so that the matrix contains the estimated impacts of the set of alternatives with respect to the set of indicators; all the AIUTO partners agreed with the production of an evaluation matrix for each test site;
- the **decision-maker***,* as the person officially responsible of the decisions and the final choice. He must take into account the presence of many ***subjects*** *or* ***groups*** involved in the decision process (generally, there are more than one interest groups and a negotiation is necessary to solve conflicts);
- the **decision model**, which considers all the indicators chosen and all the criteria used by the decision-maker in the evaluation of possible alternative.

These definitions, which obviously can also be found in approaches which are not formulated in such rigid terms, have the merit of leading to a systematic formulation of an *evaluation scheme*. This guarantees that the information is *transparent* and the path leading to the decision can be *re-traced*, so that the validity of the decision can be verified in cases of changes in a scenario or in the range of possible scenarios to be considered.

In this chapter a list of *subjects, criteria* and *indicators* is presented*.* More specifically, two lists of indicators have been identified: first, a large one, secondly a minimal list that was agreed by each test site responsible.

Subjects

- DM = decision maker
- S1 = public transport managers
- S2 = users (divided into different categories)
- S3 = social groups (representing widespread interests)
- S4 = lobbies (representing peculiar interests)

Criteria

A. **Environment** (the performance of the package towards some of the most common environmental indicators)
B. **Effectiveness** (how well the objective/goal is reached by the package – the goal being for example to limit growth of car use, to encourage public transport, to reduce congestion, etc.)
C. **Economic efficiency** (the performance of the package with respect to economic indicators, such as the IRR or the NPV)
D. **Accessibility equity** (how much the package is increasing or decreasing differences in accessibility values from zone to zone)
E. **Quality** (general quality of transport and of the territory involved by transport systems – level of service of PT network and safety indicators have been included in this group)

It should be noted that it was agreed to keep some indicators in separated groups, to better highlight their importance and the meaning they could have for road users or other subjects (see table below). For example "Environment" formed an independent item (although it could be included in the efficiency group), and Safety was considered as a part of the quality of life, as perceived by users, more than a matter of economic efficiency.

As different subjects can appreciate the various criteria in different ways, we propose a table of relations between subjects and criteria (the symbol "X" supposes a correspondence between criterion and subject).

	Criteria				
Subjects	A. Environment	B. Effectiveness	C. Econ. Efficiency	D. Acc. Equity	E. Quality
DM	X	X	X	X	X
S1 (PT)		X	X		X
S2 (users)		X	X	X	X
S3 (social gr.)	X	X		X	X
S4 (lobbies)	X	X			X

Tab. 3 - Relation between subjects and criteria

In the following two lists of indicators are proposed: *a large one* that allows a comparison of alternatives (different TDM packages) inside each test site (see chapter 5), and *a minimum one* that represents the minimal requested output for all test sites.

3.2 A Large List of Indicators

In the following a list of indicators and evaluation criteria are identified. It should be remembered that most of indicators may be detailed at different levels of aggregation (one value for each link, or zone, or users' category). It should also be noted that among general input of some of those indicators there are link flows and speeds.
In table 4 the relation between criteria (subdivided into subcriteria) and indicators can be found, as well as the relation between subjects and indicators (each criterion can be represented by different sets of indicators in relation with the considered subjects). This can lead to the proposal of organising a long list of indicators in a hierarchic way. Each indicator needs also to be related to a *reference period*, as stated before. The choice among various reference periods could be ruled by the worse-case logic (leading for example to the estimate of the peak hour conditions instead of the daily average). Other important topics are the following:

Criterion	Sub-criterion	Indicators	Subjects
A. Environment	Air pollution	CO emissions	S3 (global network) S4 (householders, in their zones)
		NOx emissions	S3 (global network) S4 (householders, in their zones)
		C_xH_y emissions	S3 (global network) S4 (householders, in their zones)
		Dust emissions (from Diesel engines)	S3 (global network) S4 (householders, in their zones)
		Population involved (at a level that exceeds the law threshold[2])	S3
	Noise pollution	Noise emissions	S3 (global network) S4 (householders, in their zones)
		Population involved (at a level of noise that exceeds the law threshold)	S3
	Energy saving	TEP (Tonns of equivalent petroleum used by road traffic and other modes).	S3
B. Effectiveness	Functionality of the whole transport system	Time spent on the transport networks	S2
		Occupancy (passengers*km / offered seats*km)	S1
		Length of congested links (private transport)	S3
		Flow/capacity ratio	S2
		Accessibility (costs on the network)	S2
		Average speed of each system	S1,S2
	Functionality of TDM policies		
	Limit growth of car use	Car kilometrage	S1
		Number of car trips	S1
	Encourage public transport	Number of public transport trips	S1
		Travel time ratio between modes	S1
		Travellers kilometrage	S1
	Encourage company based traffic management	Number of participants to company based traffic management	S1
		Presence of a co-ordination centre	S1
	Encourage car pool	Car occupancy	S1
		Number of car poolers	S1
		Number of car pool facilities	S1
	Limit car use in leisure time	Car kilometrage by trip purpose	S1
		Number of car trips by purpose	S1
	Organise Dial-a-Ride	Level of service (ratio between travel time and minimum possible travel time)	S1
	Accessibility	Accessibility of a zone (generalised cost for each origin zone to reach the other zones)	S4 (householders)
		Walking time to nearest station or stop	S2
	Disturbs	Number of transfer during a trip	S2
		Number and length of links that become congested[3] (and their localisation)	S4 (householders)

Tab. 4 – Large list of indicators (cont.)

[2] This indicator needs the use of a dispersion model, as a set of concentration thresholds is generally defined by law.
[3] You can consider a link as congested if the correspondence vehicle flow exceed 90% of its capacity.

Criterion	Sub-criterion	Indicators	Subjects
C. Efficiency	Economic	User costs (travel time, charges)	S2
		Investment costs	S1
		Net Present Value (NPV)[4]	S1
		Internal Rate of Return (IRR)[5]	S1
	Financial	Cash flow (referred to the whole system)	S1
D. Equity	Land-zones	Standard deviation of all the accessibility indicators.	S3, S4
E. Quality	Quality of service	Comfort (for each system). It could be a qualitative indicator	S1, S2
		Seated passengers*km/total passengers *km	S1, S2
		Number of public transport runs that never overcome capacity	S1
	Safety	Number of fatalities (No. of deaths, injured, accidents)	S2, S3
		Damages to the belongings	S4

Tab. 4 – (Cont.) Large list of indicators

Indicators	Possible way of estimate	Input data
CO emissions	Air pollution (emission) models	Traffic flows, vehicle categories percentage
NOx emissions	Air pollution (emission) models	Traffic flows, vehicle categories percentage
CxHy emissions	Air pollution (emission) models	Traffic flows, vehicle categories percentage
Dust emissions (from Diesel engines)	Air pollution (emission) models	Traffic flows, vehicle categories percentage
Population involved in air pollution (at a level that exceeds the law threshold)	socio-economic data	Pollutants emissions
Noise emissions	Noise pollution models	Traffic flows, site data (built form, road surface...)
Population involved in noise pollution (at a level that exceeds the law threshold)	socio-economic data	Noise emissions
TEP (Tonns of equivalent petroleum used by road traffic and other modes)	Energetic models	Traffic flows, vehicle percentage
Time spent on the transport networks	Assignment model	O/D matrices, supply
Occupancy (passengers*km/offered seats*km)	Assignment model, supply model	O/D matrices, supply
Length of congested links (private transport)	Assignment model, supply model	O/D matrices, supply
Flow/capacity ratio	Assignment model, supply model	O/D matrices, supply
Accessibility	Demand model, supply model	O/D matrices, supply

Tab .5 – Details on computing of each indicator (cont.)

[4] It is necessary to estimate a discount rate. This rate could represents one of the parameters of a scenario.
[5] IRR is the discount rate for which there is equilibrium between costs and benefits. The higher is the IRR, the safer is the project.

Indicators	Possible way of estimate	Input data
Average speed of each system	Supply, assignment model	O/D matrices, supply
Car kilometrage	Supply, assignment model	-
Number of car trips	Mode choice model	-
Number of public transport trips	Mode choice model	-
Travel time ratios between modes	Assignment model, supply model	-
Travellers kilometrage	Assignment model	-
Number of participants to company based traffic management	-	-
Presence of co-ordination centre	-	-
Car occupancy	Mode choice model	-
Number of car poolers	-	-
Number of car pool facilities	-	-
Car kilometrage by travel purpose	Assignment model	-
Number of car trips by purpose	Generation model - surveys	O/D matrices - socio-economic data
Level of service (ratio between travel time and minimum possible travel time)	Mode choice model	O/D matrices
Accessibility of a zone (generalised cost for each origin zone to reach the other zones)	Supply, assignment model, demand models	O/D matrices, supply
Walking time to nearest station or stop	Supply model	-
Number of transfer during a trip	Mode choice, assignment choice	-
Number of links that become congested (and their localisation)	Assignment model, supply model	O/D matrices, supply
User costs (travel time, charges)	Supply, assignment models	Supply, fares, Value of time (for different users)
Investment costs	Exogenous data	-
Net Present Value (NPV)	Exogenous data	Revenues, costs, discount rate
Internal Rate of Return (IRR)	Exogenous data	Revenues, costs.
Cash flow (referred to the whole system)	External data and assignment models (for exercise costs)	debit and credit for each transport system
Standard deviation of a set of accessibility indicators	(Multi-user) supply, assignment models	(Multi-user) supply, fares, Value of time (for different users)
Comfort (for each system). It could be a qualitative indicator	Qualitative indicator (high, middle, low)	-
Seated passengers*km/total passengers *km	supply, assignment model	number of seats per vehicle, total capacity of each vehicle.
Number of public transport runs that never overcomes capacity	Assignment model	number of seats per vehicle, total capacity of each vehicle.
Number of fatalities	Car accident model (a model that relates fatalities and accident with traffic flows)	Traffic flows
Damages to the belongings	Car accident model (a model that relates fatalities and accident with traffic flows)	Traffic flows

Tab. 5 - (Cont.) Details on computing of each indicator

- the decision maker *is always involved*;
- not only criteria but also sub-criteria for effectiveness of TDM packages should be considered;
- each subject can obtain its criteria combining the indicators in different ways.

In table 5 (page 24), all indicators are listed and the possible ways to estimate them as well as the required input data are specified for each indicator (the criteria are omitted as they are the same as the previous tables.

3.3 The Minimum List of Indicators

The AIUTO project involved different case studies (*test-sites*, see chapter 5), so it raised the need to use a minimum list of common indicators to compare the results among case studies.
This minimum list is a list for this project only, and in the following table there is the least list of indicators agreed. Some of these indicators can be estimated by the use of the transportation and environmental models that will be described in chapter 4. On the other hand, some indicators could be estimated or calculated by the use of exogenous data. In Tab. ? a possible way of estimate for all the indicators required is suggested.
Each row represent an indicator, the related criterion, the least type of the representation required (qualitative, numerical...), and a possible way of estimation.
For the reference period the average peak hour is proposed. Evaluation can be based on the short-medium *time horizon*. On the other hand an indicator like "land use impact" is introduced for evaluating long term effects.

Criterion	**Indicator**	**Minimal type required**	**Possible way of estimate**
Environment	Total emission of CO	Numerical	CORINAIR model
Effectiveness	km, by mode	Numerical	Transport models
	No. of trips, by mode	Numerical	Transport models
	Total accessibility	Numerical	Transport models
Efficiency	Change in consumer surplus	Numerical	Transport models
	Investment costs	Qualitative (low, medium, high)	Exogenous estimate
	Operational costs	Qualitative (low, medium, high)	Exogenous estimate
Quality	Average speed (as a "proxy" of safety)	Numerical	Transport models
	Land use impact	Qualitative	Exogenous estimate
Equity	Worst case in the accessibility change	Numerical	Transport models
	Equity indicator	Numerical	Transport models

Tab. 6 - The minimum list of indicators

While some of the above indicators are easy to calculate (the amount of km and the no. of trips, which are only sums) some others (in particular those indicators related to the generalised cost calculation) are more complex.
In the following pages the indicators above will be explained and way for computing will be proposed. However it is important to note that this is not the unique calculation method, as the method may depend on the model used (static or dynamic, etc.).

Total Emission of CO

Abbreviation E^{co}
Type Numerical
Measure unit g
Formula $E^{CO} = \sum_i lenght_i * \left[\sum_{vc}\left(IMP_{i,vc} * flow_{i,vc}\right)\right]$

where:

i = 1...n	links of the network
vc = 1...26	vehicle classes (according to CORINAIR model)
$lenght_i$	length of the link i
$flow_{i,vc}$	flow on the link i for the class vc
$IMP_{i,vc}$	impact per vehicle class and unit length on the link i

IMP_{vc} is calculated by the CORINAIR model, knowing the vehicle class and the average speed on the link.

No. of Kilometres by Mode

Abbreviation VEHKMm
Type Numerical
Measure Unit vehicles*km
Formula $VEHKM_m = \sum_i length_i * flow_i^m$

where:

m	mode of travel
i = 1...n	number of links of the network
$length_i$	length of the link i
$flow_i^m$	vehicle flow on the link i for the mode m

No. of Trips by Mode

Abbreviation TRIPSm
Type Numerical
Measure Unit N° of Trips
Formula $TRIPS_m = \sum_o \sum_d trips_{od}^m$

where:

m	mode of travel (i.e. private transport, bus, rail...)
o = 1...z	origin zones in the network
d = 1...z	destination zones in the network
$trips_{od}^m$	number of trips from origin “o” to destination “d” by mode m

Accessibility

Abbreviation A
Type Numerical
Measure Unit generalised cost
Formula The total accessibility A is equal to the zonal accessibilities Ao. (or Pd) sum. A zonal accessibility is the sum of the travelling costs to reach all the other zones from a given zone “o” (active accessibility A_o), or, from another point of view, the sum of the travelling costs to reach a given destination “d” from all the other zones (passive accessibility P_d).

The total accessibility quantifies the opportunities for an easy exchange between zones in a city; a goal of the TDM policies should be to reduce this indicator (with respect to the “do nothing” alternative).

$$A = \sum_o A_o = \sum_d P_d$$

where:

o = 1...z	origin zones in the network
d = 1...z	destination zones in the network
z	total number of zones
$A_o = \sum_d c_{od}$	generalised cost necessary to reach all the other zones starting from o
$P_d = \sum_o c_{od}$	generalised cost necessary to reach the zone d from all the other zones
c_{od}	the generalised cost connected to the use of the different mode of transport available on the o/d couple. It is the same as the generalised cost of the single mode only if it is applied to a monomodal network.

Consumer Surplus

Abbreviation	DCS
Type	Numerical
Measure Unit	Monetary value
Formula	$\Delta SC = \sum_o \frac{1}{2}\left(d_o^A + d_o^0\right)\left(\overline{C}_o^0 - \overline{C}_o^A\right)$

where:

d^A_o	total demand from origin “o” in the alternative A.
d^0_o	total demand from origin “o” in the alternative 0.
$\overline{C}_o^A = \sum_{dmk} p_{dmk/o} C_{dmk}^A$	average cost to reach all destinations d by all modes m with paths k in the alternative A.
$\overline{C}_o^0 = \sum_{dmk} p_{dmk/o} C_{dmk}^0$	average cost to reach all destinations d by all modes m with paths k in the alternative 0.
$p_{dmk/o}$	fraction of trips from origin o to destination d by mode m and path k. For each origin o the sum of $p_{dmk/o}$ is equal to 1.

Investment Costs

Abbreviation	CI
Type	Numerical or Qualitative (lowest requisite)
Measure Unit	Monetary value (or symbol)
Formula	It is requested at least a qualitative evaluation, based on the following category:

low	applicable to TDM measures that do not require purchase of equipment, vehicles or building of infrastructure (e.g. parking pricing policies)
medium	applicable when the investment costs are only for the electronic control system of the access and the for management demand centre (e.g.: Dial-a-Ride, car pool), but not for the infrastructures and/or vehicles.
high	applicable for measures that require purchasing or building of infrastructures and/or vehicles.

Operational Costs

Abbreviation	CO
Type	Numerical or Qualitative (lowest requisite)
Measure Unit	Monetary value (or symbol)

Formula — It is requested at least a qualitative estimate, based on the following categories: *(low, medium, high)*

Average Speed

Abbreviation — S
Type — Numerical
Measure Unit — km / hour
Formula[6]

$$S = \frac{\sum_i speed_i * flow_i}{\sum_i flow_i}$$

where:

$speed_i$	medium speed on the link i
$flow_i$	vehicle flow on the link i for the private mode

Land Use Impact

Abbreviation — LUI
Type — Qualitative
Measure Unit — This indicator contains a subjective estimation of what the effect on land use will be, due to the application of proposed TDM's.
The indicator is evaluated qualitatively, in a Low-Medium-High scale. Possible effects to be taken into account are: re-distribution of productive activities, increasing or decreasing of commercial "attractiveness", change in residential land price, necessity of building main new infrastructures, etc.

Worst Case of the Accessibility Change

Abbreviation — DA
Type — Numerical
Measure Unit — Monetary value
Formula[7]

$$\Delta A = \max_o \left(A_o^A - A_o^0 \right)$$

where:

ΔA	Worst case of the accessibility change
o = 1...z	origin zones in the network
z	total number of zones
$A_o^A = \sum_d c_{od}^A$	Active accessibility of the zone "o" in the alternative A, i.e. generalised cost necessary to reach all the other zones starting from "o"
$A_o = \sum_d c_{od}$	Active accessibility of the zone "o" in the alternative 0, i.e. generalised cost necessary to reach all the other zones starting from "o"
c_{od}	the generalised cost connected to the use of the different mode of transport available on the o/d couple. It is the same as the generalised cost of the single mode only if it is applied to a monomodal network.

Equity Indicator

Abbreviation — Q

[6] This indicator is calculated only on the private transport network and can be considered a "proxy" of safety.
[7] The application of a TDM scheme probably creates a decrease of A_o in certain zones and (on the other hand) an increase in other ones. This effect is highlighted by the worst case of the changes in the zonal accessibility.

Type	Numerical
Measure Unit	Number
Formula	A situation is more unbalanced when the standard deviation of the total accessibility is higher. So an indicator of equity among zones could be the ratio between the standard deviation and the average of the active accessibility A_o. The better case for this indicator is 0.

$$Q = \frac{S_d}{\overline{A}} = \frac{\sqrt{\frac{\sum_o \left(A_o - \overline{A}\right)^2}{z}}}{\frac{\sum_o A_o}{z}}$$

where:

z =	number of zones
o = 1...z	origin zones in the network
d = 1...z	destination zones in the network
A_o	active accessibility of zone i
$\overline{A}$ =	average of the active accessibility
S_d	standard deviation of the active accessibility
c_{od}	The generalised cost connected to the use of the different mode of transport available on the o/d couple. It is the same as the generalised cost of the single mode only if it is applied to a monomodal network.

4. MODELS

4.1 Introduction

In this section models used to simulate the effects of TDM measures will be briefly treated.
The contents of this chapter are closely related to the report "APAS Urban 2 Modelling Project - Modelling of urban Transport" edited by the *Directorate General Transport (DGVII)* of the European Commission, 1996. AIUTO treats almost all the arguments treated in APAS. However, with respect to APAS, a deeper description of the theoretical and technical background and formulation of the models has been preferred to the wider general and comprehensive approach of APAS. It results that AIUTO can be reviewed as an analytical complement of some of the appendixes the APAS documentation gets through. The modelling classification presented in this report is substantially coincident with the one stated in APAS.

In order to summarise all the groups of models reviewed, studied and used in the AIUTO project, a hierarchical classification of all models is given in the following box.

Transportation Models
"Non integrated models" in the APAS terminology. All models needed to compute the transport indicators for the MOE's stated in chapter 3

- Demand Models
Models which reproduce the demand to make journeys by people in a specified study area and in a specified day or time of day

- Holding vs. Switching Models
- Aggregated vs. Disaggregated Models
- Behavioural vs. Descriptive Models
- Logit and Probit models

- Supply and Assignment Models
Models which reproduce the transport networks characteristics and allow the demand to be "assigned" onto the supply, reproducing the network flows

- Congested vs. not Congested Networks
- Within Day Dynamics vs. Day to Day (or inter-periodic) Dynamics
- Deterministic vs. Stochastic User Equilibrium Models
- Single User vs. Multi-User Assignment

Environmental Models
"Evaluation models" in the APAS terminology. All models needed to compute the environmental indicators for the MOE's stated in chapter 3

- Air Pollution Model

- Emission Models

- Dispersion Models

- Noise Pollution Models

- Fuel Consumption Models

4.2 Transportation Models

In the following pages a brief classification of the demand models will be explained. For a detailed description of each model the reader should refer to Deliverable D.4.2.
In the following table the relationship between the user choices, the sub-model used and the classification into two main “groups” of models can be observed[8].

Sub-Model	**Demand choice to be modelled**	**Group**
Activity time (time band) choice	Activity/departure time choice	Demand models
Trip generation	Trip frequency choice	
Trip distribution	Destination choice	
Modal split	Mode choice	
Parking	Parking choice	Supply and assignment models
Mixed modes	*(it can be part of the mode choice)*	
Route choices	Route choice	

Tab. 7 - Specific sub-models

4.2.1 Overall Structure

A general overall structure of a model system is shown in Fig. 8. Solid lines represent relationships of dependence while dashed lines represent relationships of influence. Any decision level, excluded the first and the last, is conditioned by the choice carried out at the higher one, and is influenced by the expected utility relative to the lower levels. Thus, for example, mode choice is conditioned by the destination to be reached and at the same time, can influence the choice of such a destination.
The sub-model sequence can be, in theory, established in any way; in practical use the sequence corresponds to a given hypothesis of the rank in which the level of choice are faced by the users (in principle this rank could be different for different trip purposes or users’ socio-economic characteristics). The hypotheses on the sub-models succession can be (should be) verified in phase of calibration and validation of the models.
Once the choice set for each sub-model has been defined, each one produces as an output the probabilities that an individual chooses an alternative.

The probability of choosing an elemental alternative, facing the whole decision process from trip frequency to route choices, is the product of all the conditional probability relative to the choice outcomes at the different decision levels:

$$p(trip, activity, dest, mode, time, park, route) = p(trip) \cdot p(activity \mid trip) \cdot p(dest \mid trip, activity) \cdot p(mode \mid trip, activity, dest) \cdot p(time \mid trip, activity, dest, mode) \cdot p(park \mid trip, activity, dest, mode, time) \cdot p(route \mid trip, activity, dest, mode, park, time)$$

[8] The overall demand pattern is the result of several travel and mobility choices such as driving license holding, car ownership, trip frequency, activity time (time band), trip destination, mode, route, parking type and location, departure time etc. Within a system of demand models these different choices are generally referred to as “level of choice”. Generally choices like driving license holding and car ownership are considered as belonging to an upper group-level, they are conventionally referred to as “mobility choices” while the others are generally referred to as “travel choices”. The mobility choices imply a larger cost to be changed with respect to the travel choices, so they are more time-stable, and will be not treated within AIUTO.

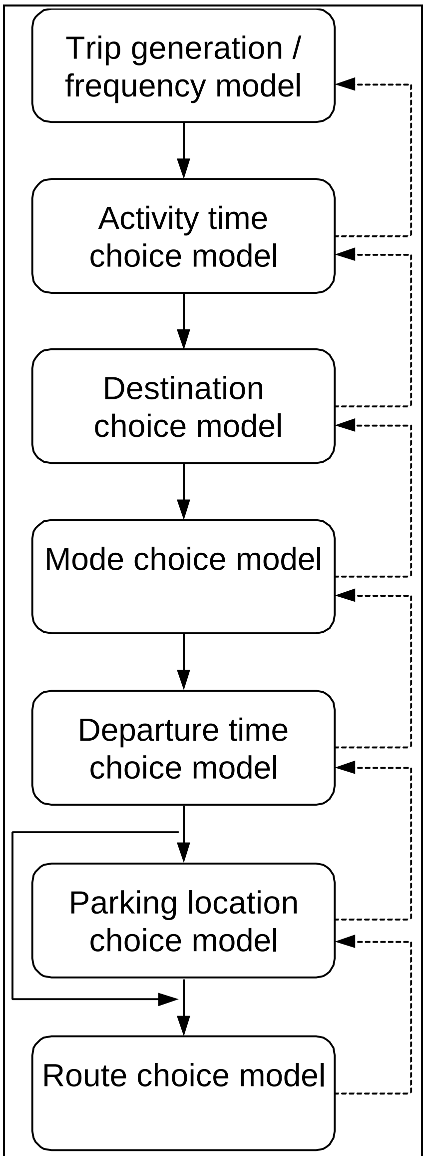

Fig. 8 - General structure of transportation models

4.2.2 Demand Models

In the following the demand models are classified per approaches and per specification.

Model Approaches

One of the most fundamental, well known and widely accepted principles is that **travel demand** is derived from **activity demand**. This principle is due to the fact that the decision framework includes travel decisions as components of a broader activity scheduling decision, and it requires the demand for activities to be modelled. Starting from a daily schedule it is possible to derive a tour pattern. The problem is very complex because of the very large number of activities to take into account. Travel demand models deal with this problem following three different approaches:

Model approaches	**Description**	**State of the art**
Trip based approach	restricts itself to each trip of the *daily trip chain* which is separately (even if consistently) simulated, in the sense that the travel choices related to a trip are not influenced and do not influence the other trips of the chain.	The oldest and consolidated approach.
Tour approach	restricts it attention to the travel pattern, but the sequence of different trips of the same chain is explicitly and consistently considered in order to satisfy a fixed and exogenous activity pattern.	Few models implemented.
Activity based model	directly starts from the consideration that travel demand is a derived demand and in order to determine the demand pattern, the activity pattern could be usefully investigated.	Only research.

Tab. 9 – Model approaches

In the following figure such three subclasses are compared by seeing how they represent a hypothetical daily schedule. In this schedule the person departed for work at 7:30 AM, travelling by transit. At noon he walked out for personal business, returning to work at 12:50 PM. At 4:40 PM he came back home from work, again by transit. That evening at 7:00 PM he drove to another location for shopping, returning home at 10:00 PM. The trip-based model represents the schedule as 6 one-way trips. The “direction” of the trips is in terms of trip production and attraction rather than direction of movement. Time is not modelled explicitly. In the tour-based model trips are explicitly connected in tours, introducing spatial constraints and direction of movement. Finally, the daily schedule model explicitly links the tours and explicitly models the time dimension, although at a coarse resolution.

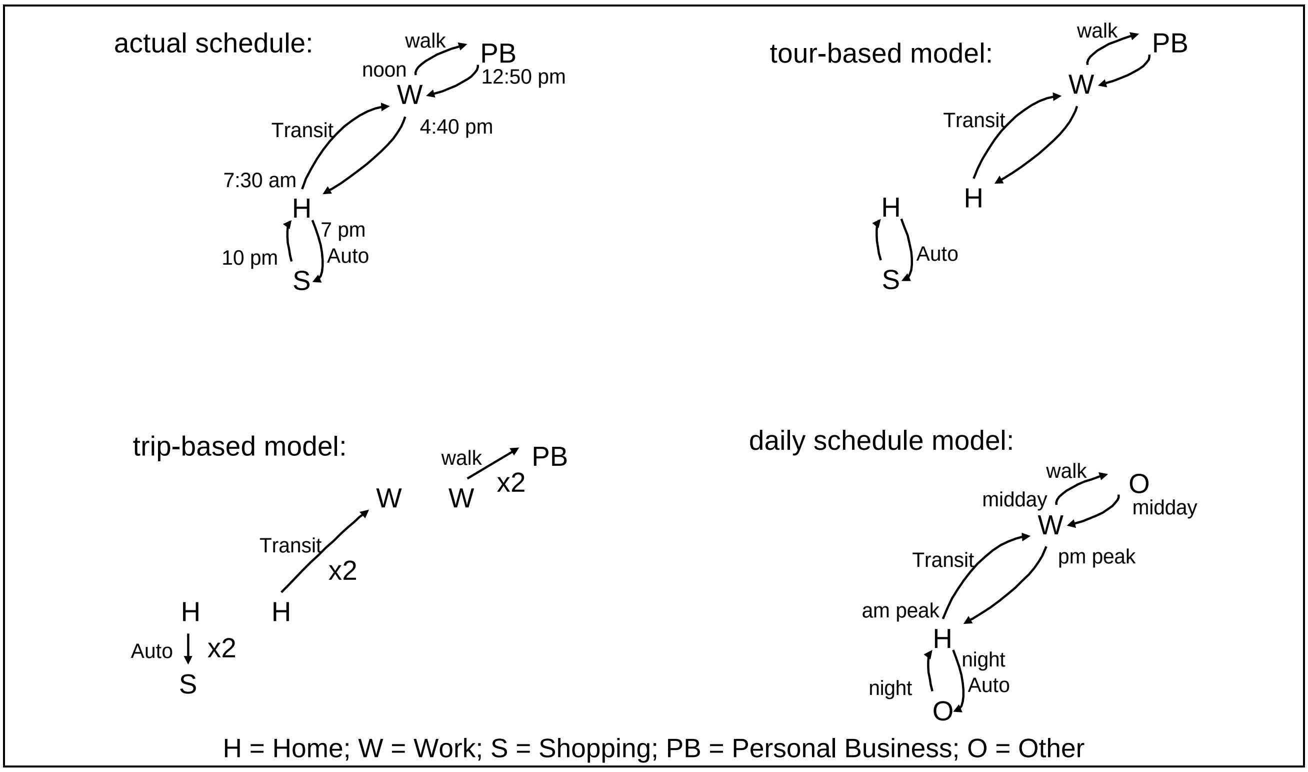

Fig. 10 – Demand models approaches (trip based, tour based, daily schedule)

Model Specification

Holding or Switching Models

Holding models estimate the overall demand pattern, *switching models* estimate the marginal increment of the demand due to a change in the transportation system.

Aggregated or Disaggregated Models

A demand sub-model is said to be disaggregated if the variables it depends on (referred to as *attributes*) are related to the real characteristics of each user. In practice completely disaggregated sub-models do not exist. Sometimes they are calibrated in a disaggregated way and applied in a semi-disaggregated manner, where the users are grouped into proper classes (characterised by similar attributes with respect to the handled choice/s).

Behavioural or Descriptive

Demand sub-models are said to be behavioural or descriptive depending on if explicit behavioural assumptions are made in order to simulate the users’ choices with respect to the attributes or if only the relationships between the attributes (explicative variables) and the choices (explained variables) are analytically described. In practical use the most used systems of sub-models are of a mixed type both in reference to the disaggregation and behavioural assumption.

Logit or Probit

The specification of each sub-model is generally based on random utility models which are typically specified in a LOGIT or PROBIT form (as also stated in APAS). On the other hand, the specification of each level of choice within a given sub-model, as well as the overall choice structure of the whole system of models can be faced within a hierarchical approach which, typically, leads to Tree-Logit (or Nested-Logit) structures.

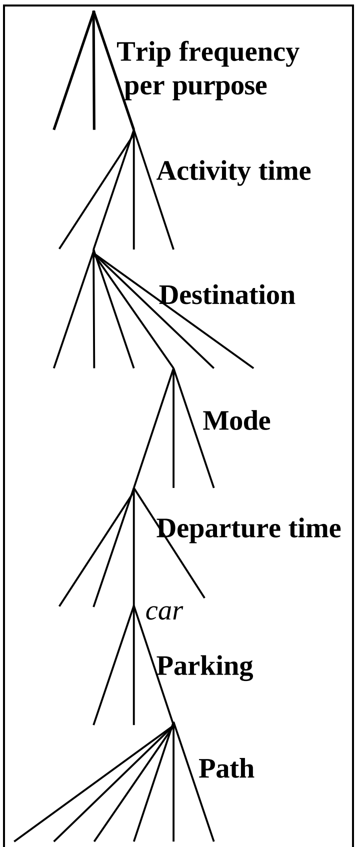

Fig 11 - Outline of the tree structure for all choice levels

This structure is by now largely used in demand forecasting, applying it either entirely on the whole sequence or partially on some of trip decisions. Its mathematical structure also allows two successive decision levels to be contracted into one, and contains, in the utility functions of any level but the last, a “logsum” term proportional to the perceived satisfaction relative to the whole set of the available alternatives at the lower level. In figure ?? an outline of a tree structure is shown, relative to all the choice levels of the system of models represented in figure 8.

At each level *k*, the conditional probability of an individual *i* choosing an alternative *j* among the set of alternatives available at such a level to him/her, can be written in the Logit form:

$$p^i(j_k) = \frac{\exp(V_j)}{\sum_{j' \in J^i_{ik}} \exp(V_{j'})}$$

in which J^i_k is the set of alternatives available at level *k* to the individual *i*, and the systematic utility function V_j include the logsum term Y_k proportional to the satisfaction due to the perceived utility of the alternatives available at the lower level *k+1*:

$$V_j = b_k \mathbf{X}_k + d_k Y_k \qquad \forall j \in J^i_k$$

$$Y_k = \ln \Sigma_s \exp(V_s) \qquad \forall s \in J^i_{k+1}$$

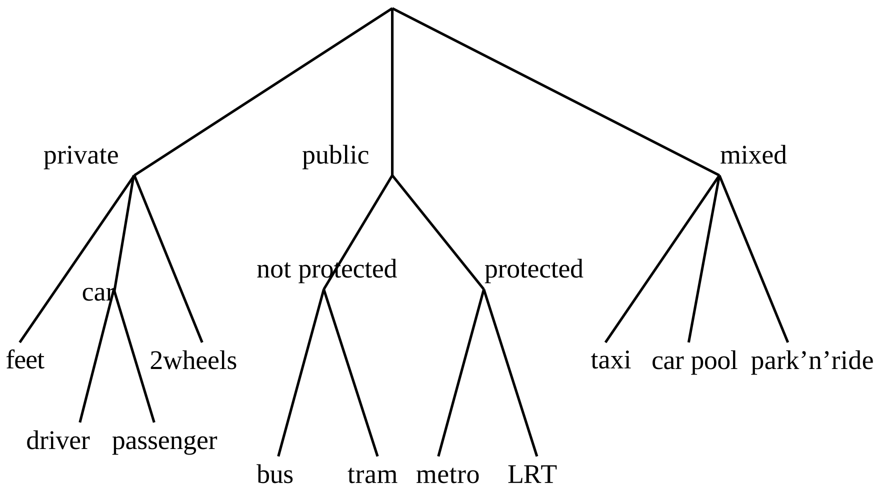

Fig. 12 - Example of a "within sub-model" tree-Logit choice structure (mode choice model)

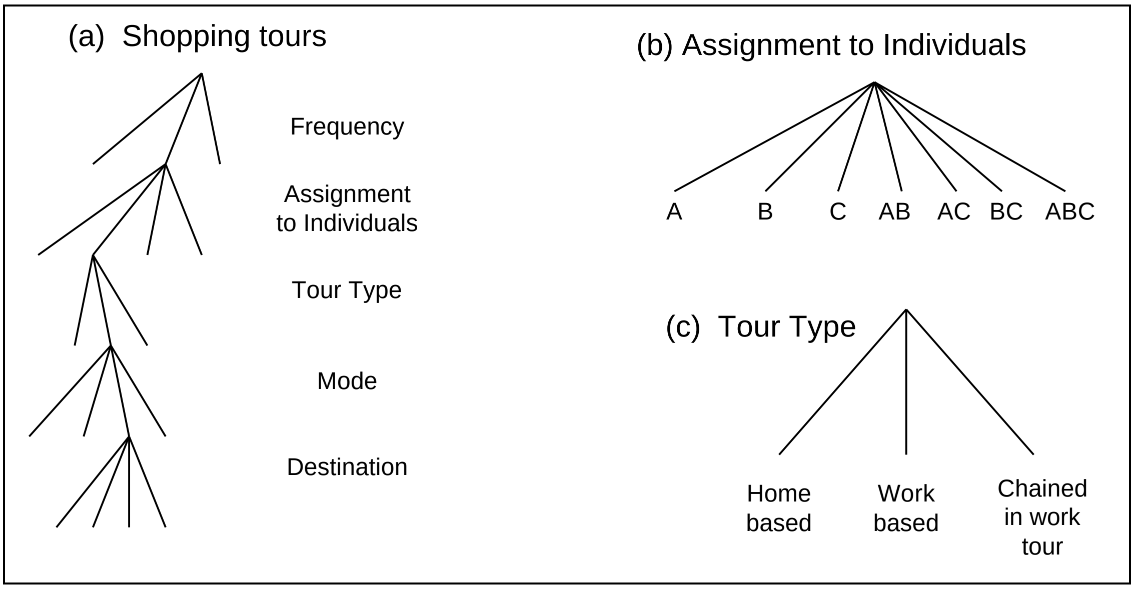

Fig. 13 – Example of a tour based model. For shopping tours (Stockholm model)

4.2.3 Supply and Assignment Models

Supply models aim to reproduce in an analytical way the phenomena occurring (or induced) on the transportation system during its use, while the assignment models aim to reproduce the users' choices in using the transportation system.

The assignment models are strongly related to the problem of interaction between transportation demand and supply: the users' choices depends on the system performances, on the other hand they determine the loading of the transportation system, which in turn influence the system performances.

From a very general point of view, the supply system could be defined as an **infrastructured space** on which objects move, giving rise to **flows**. A huge set of variables could be associated to the infrastructured space and to the flows.
With such definitions, a first classification of the supply modelling approaches could be made with respect to criteria regarding *space*, *time* and *flow* discrete or continuous modelling: *time* and *space* could be *discrete* or *continuous*, *flows* are theoretically discrete (the number of moving objects is finite and discrete by definition) but they can be modelled, for analytical convenience, as continuous variables, moreover flows can be modelled in an *aggregate* or *disaggregated* manner.

		FLOWS	
SPACE	**TIME**	Aggregated	Disaggregated
Discrete	No representation	Within-day-static	
	Discrete	Within-day-dynamic	Microsimulation
	Continuous		
Continuous	Continuous	Flow theory	

Tab. 14 – Model classification with respect to space time and flow.

It could be useful to fix the previous concepts by mean of some examples.

- Supply modelling based on the flow theory (e.g.: Prigogine and Hermann):
  - ∗ time is continuously represented;
  - ∗ continuous space representation; the characteristics of the infrastructured space are defined in each point;
  - ∗ aggregate flows representation; the representing variables are frequently associated with space via “density-type” functions, which are continuously defined for each point of the space.
- Network within-day-static supply models (i.e.: EMME/2, TRIPS, ...):
  - ∗ no time explicit representation;
  - ∗ discrete space representation; the infrastructured space is modelled through links and nodes, variables are associated (in a discrete number, but they can take continuous values) with links and nodes and the real position within each link/node is neglected;
  - ∗ aggregate flows representation; in these models flows represent moving objects (vehicles and/or passengers) but the representing variables are not associated with objects, rather it is defined an associative property of these objects to link and/or nodes (for example: an average speed is associated with all objects, or groups of objects, entering a cross section of the generic link); the links and/or nodes being discrete, the flows and their associated variables are in discrete number too.
- Network within-day-dynamic supply models:
  - ∗ time could be treated as continuous or discrete;
  - ∗ space is discretely represented, as in network static models;
  - ∗ flows representation could be either aggregated or semi-disaggregated; if aggregate, flows (and related variables) are associated to links (though a different definition of flow is given, taking into account also time); if semi-disaggregated, objects are grouped into packets (within packets the objects representation is aggregate) and their movements along links allow evaluation of the associated variables (so, variables are referred to both packets and link).
- Microsimulation supply models:
  - ∗ time could be continuously or discretely represented, as for dynamic supply models;
  - ∗ space is discretely represented, as for network static and dynamic supply models;
  - ∗ flows (and related variables) are disaggregated, each object is separately represented.

Transport Mode

A big difference exists between private networks and transit networks. The latter ones are more complicated because the route choice process must take into account the constraints due to the transit lines, the boarding penalties, the time needed to access to the transit facilities, while the private network is easily accessed by the car drivers from everywhere. Some detailed models could follow an hypernetwork approach, where both private and public modes are simulated. In this case the mode choice is explicitly modelled through the network.

Congested and not Congested Networks

From an analytical point of view congestion simply means that the flow values have a mathematical influence on the values of the variables associated to flows. For example, in network static models, the supply model is said to be congested if the value of the flow on a given link influences the speed of the flow on the link itself and (possibly) on other links. The congestion phenomena give rise to the demand/supply interaction problem.

Within Day and Day to Day Dynamics

Most existing assignment models (for congested networks) follow a (deterministic or stochastic) *equilibrium* approach, defined by a link flow pattern in which no user can improve the (systematic or perceived) utility of his/her choice by unilaterally changing it. The *inter-periodic (or day-to-day) dynamic* approach follows a different approach. First of all, it allows the simulation of some

relevant aspects such as transients, temporal fluctuations and multidimensional dynamics with different "propensity to change" over different choice dimensions (e.g. activity location, trip frequencies and distribution, mode and path choices). Moreover inter-periodic dynamic models can be seen as a tool for the analysis of theoretical properties of system convergence to different attractors (not necessarily equilibrium or fixed-point) such as existence, uniqueness and stability. From this viewpoint these models could also be called *disequilibrium* models, whilst the equilibrium models could be considered *day-to-day (or inter-periodic) static*.
Two types of day-to-day dynamic process models can be formulated.

- *Deterministic process* models, based on non-linear dynamic system theory, can be used to analyse the asymptotic behaviour of the system. They can also be used to study equilibrium properties, since the equilibrium state can be seen as a fixed-point attractor of a deterministic process under some hypotheses on users' learning mechanisms and switching behaviour.
- *Stochastic process* models based on stochastic process theory, allow an explicit simulation of the intrinsic randomness of both demand and supply.

Deterministic and Stochastic User Equilibrium Models

The assumption of Deterministic User Equilibrium models is the cost minimising users' behaviour based on perfect knowledge. On the other hand, some authors proposed assignment models based on route choice models which distribute users among several paths besides the shortest ones. Most route choice models were developed, or can be cast, within the framework of random utility theory, thus referring to the travel demand paradigm introduced in the early 70's. These assignment models are labelled as Stochastic.

Single User and Multi-User Assignment

The assignment is called "multi-user" when the cost are perceived differently by different users categories. A multi-user assignment model poses the following problem (Daganzo, 1983): "take into account that different users categories jointly determine the congestion of the same infrastructure, so that the route choices of each category could possibly influence the transportation system performances for all the users categories".

4.2.4 The AIUTO Framework

Generally a model suite for simulating transportation systems and policies is made up by several highly interrelated components. For example, a conceptual description of the main logical components of such a modelling suite is shown in the following figure.

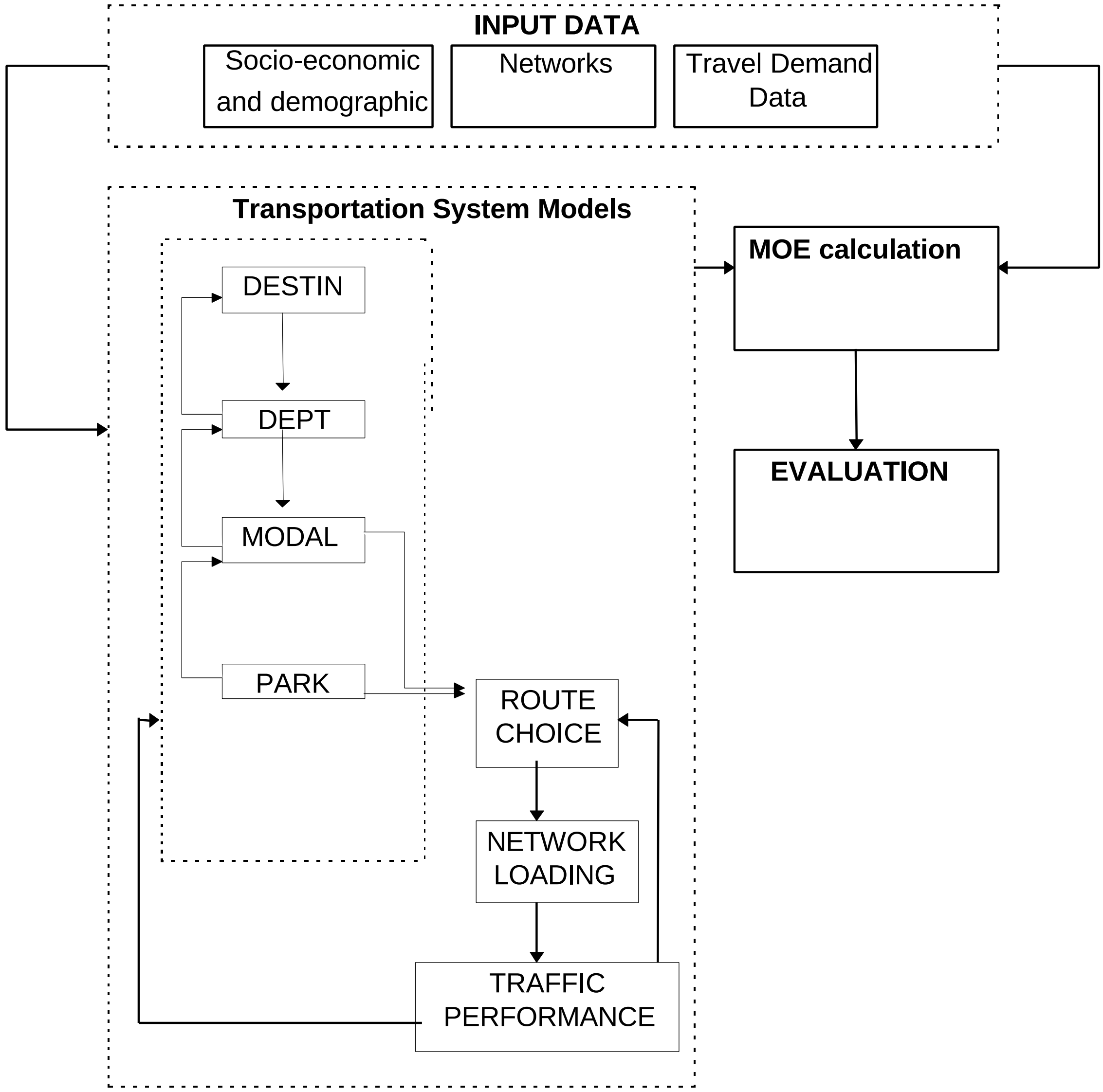

Fig. 15 – AIUTO framework
Where:
DESTIN = Destination choice model
DEPT = Activity time choice model
MODAL = Mode choice model
PARK = Parking choice model
ASSN = Assignment model.

In this framework it is possible to recognise the **input data** box composed of three categories of data which will be defined in detail in chapter 5: socio-economic / demographic data, networks and travel demand data.
Inside the **transportation models** it is possible to identify the **demand models** box composed of a set of sub-models which predict the travel related choices of the users (they are destination choice, departure time choice, mode choice, parking choices) in order to produce an OD matrix to be assigned onto the network using the **assignment procedures (**composed of a **route choice model,** a **network loading model** and a **traffic performance computation procedure)**. All these procedures and models depend on the previous model results, but can also influence them. This is the reason for the feedback lines, meaning that several runs of the system models must be performed until a general equilibrium between supply and demand is reached.
The Travel Demand Data should be obtained by estimating the present overall mobility level and the activity timing, as well as spatial and modal distribution of the demand. The Transportation

System Models should calculate the modification of such a current distribution given by the application of TDM strategies.
The architectural framework of the models must be also integrated with the models for MOE calculation (e.g. environmental models) and by the evaluation models (i.e. such procedure which is able to produce a ranking of the alternatives, by comparing one or more TDM packages' effects and the do nothing situation).
This framework is consistent with the general objective of AIUTO which is to assess the effects of a TDM strategy as defined in chapter 2. For example the proposed framework allows the modeller to simulate the change of the temporal peaks of car demand (DEPT) and the change of the spatial concentration of car demand (DESTIN and PARK).
The general framework is a complete set of models able to simulate all the TDM measure. Not all of the models were applied in each case study (see sections 5.2-5.7): it depended on the simulated scenarios.

4.3 Environmental Models

We propose in the following a concise survey of the principal models of simulation in terms of emission and pollution concentrations and other environmental effects caused by traffic.
Environmental models aim to estimate impacts caused by road traffic. In this report they are classified in the following categories.

- Air pollution models, divided into:
  - emission models,
  - dispersion models;
- Noise pollution models;
- Fuel consumption models.

Traffic flows on the network (calculated by road assignment models) are the common input data for all these models. Other inputs can be the meteorological conditions (wind speed and direction), orography, terrain raggedness and other specific features (APAS 1995).

4.3.1 Air Pollution Models

The problem of air pollution caused by road traffic can be subdivided into emission of gaseous and fine particulate pollutants, and their dispersion in the atmosphere. Emission and dispersion models produce a complete composite model that calculates pollution concentrations from traffic, emission rates and meteorological input data. However, to assess environmental effectiveness of TDM policies, it could be enough to use only emission models, considering the reduction of the global pollutant emissions as the priority objective.
On the other hand we need to consider that only the use of dispersion model allows quantitative estimation of the benefits of the reduction in pollutants concentration. The estimate of one of the indicators proposed in the large list of chapter 3 ("Population involved from a level that exceed the law threshold") needs the use of a dispersion model.
In the following there is an explanation of both types of models.

Emission Models

Emission models (SAVE 1996) relate vehicle emission rates to some traffic variables such as:

- driving conditions (e.g. average speed, congestion levels and, in certain cases, driving mode estimated with road assignment models);
- vehicle characteristics (e.g. engine type and size, vehicle age, vehicle maintenance and use of catalytic converters, by measured data).

The different types of emission rates that can be used, individualise three subcategories of emission models, suitable for different scales of analysis.

- *Macro area models (e.g. region)*: emission rates are related to the average speed of a trip and the type of vehicle (age, petrol-diesel powered, passenger car or heavy vehicle); these models ignore driving modes, queuing processes and are suitable for analysis where total emission estimates per vehicle trip are sufficient (example: CORINAIR model).
- *Micro area models (e.g. intersection)*: these models requires space-time trajectories for individual vehicles as input data; they relate the vehicle instantaneous emission rates to its instantaneous speed and acceleration; these rates are then aggregated to predict emissions per driving mode and per road link (example: Automobile Emission Modal Analysis Model, U.S. Environmental Protection Agency).
- *Intermediate models (e.g. urban area)*: in these models the number of vehicles per mode of motion (accelerating, decelerating, queuing, cruising) is estimated for each road link (based on the queue length); emission rates are disaggregated by mode of motion; queue lengths are estimated using shock wave theory at signalised intersections and stochastic queuing theory at priority junctions (example: UROPOL).

Dispersion Models

Dispersion models aim to estimate the concentration of each pollutant in every location and time, given a system of pollutant sources. These model require these type of data:

- location of the emissions and their amount;
- meteorological factors, such as wind speed and direction, temperature of the air;
- rates of any chemical reaction that may occur.

Also these model may be distinguished into three categories; the discriminating factor is the way the relation between emission and concentration is simulated.

- *Analytical models*: they are based on the specific solutions of the transport-diffusion partial differential equation, in the hypothesis of homogeneity and stationarity of emissions and meteorology; the most important models of this category are based on gaussian plume[9], the source of emission can be a point or a line (for example a road); these models are very commonly used to predict dispersion of pollutants caused by road traffic, even if they cannot give models for the effects of chemical reactions in the atmosphere.
- *Eulerian models*: they are based on the direct numerical integration of the transport-diffusion partial differential equation (conservation of mass in a turbulent flow), and can include explicitly the chemical reactions among pollutant species; these models can consider relationships between emissions and concentrations of chemically reactive pollutant species involving non linearities (e.g. ozone formation from nitrogen oxides and hydrocarbons).
- *Statistical models*: the relation between emission and concentration is performed by statistical techniques, such as regression analysis (they are not frequently used in practice).

The wind speed vector representation on the territory (important information for the dispersion) can be also obtained by the *wind-field simulation models*, that use as an input the direction and the speed of the non perturbed wind at high altitude (geostrophic wind), and the terrain orography and raggedness. These models can be of interest for cities developed on territory with an uneven orography.

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[9] The Gaussian plume is a normal distribution centred on the plume's axis. When the source is puntiform the formula is:

$$C_{xy0h} = \frac{Q}{\pi u \sigma_x \sigma_y} e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} e^{-\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2}$$

C_{xy0h}	Concentration in a point x, y, 0, with emission height h (the source is at the point 0,0,h)
Q	emission flow
u	wind speed
σ_x, σ_y	standard deviations of the concentration distribution.

4.3.2 Noise Pollution Models

These models aim to predict noise levels from road traffic at a receptor point and require these types of data:

- traffic factors (e.g. flows, speeds, percentage of trucks);
- environmental factors (e.g. road surface, presence of any obstructions);
- estimated basic noise parameter.

The measuring of traffic noise can be based upon the assessment of various noise levels, both in day- and night-time. Among the available indicators, one of the easiest to compute (although not extremely detailed) deals with the evaluation of the noise level over a given period of *n* hours (for example 18 hours, generally from 6 AM to 12 PM). Significant levels are the following:

- $L_{90}(n)$ - the level exceeded 90% of the time,
- $L_{50}(n)$ - the level exceeded 50% of the time,
- $L_{10}(n)$ - the level exceeded 10% of the time.

For the estimate of these levels there are two categories of noise models.

- *Empirical/mathematical models*: they use charts and tables and need relevant site data. They are very useful for a single situation but unreliable for a complex screening configurations (an example is the CRTN model, UK Department of Environment). Some computer versions of the mathematical models can be used for a wide variety of road configurations (an example is the CROSECT model, developed by TRL).
- *Scale model*: this model needs a prototype and can predict noise level for various screening configurations. On the other hand this model requires a very complex and expensive system of instruments (it is mentioned only for completeness).

4.3.3 Fuel Consumption Models

These models aim to predict the fuel consumption of a vehicle. Fuel consumption depends on a complex set of variables including, but not limited to, distance, travel time, vehicle acceleration and deceleration and gradient of roads used.
They have an analytical form, often a simple linear relationship between a set of independent variables and the consumption (dependent variable). In the set of the independent variables a lot of data can be used, estimated by a road assignment model (for example flows and speed) and, if more details are needed, by a simulation of traffic queuing (for example: total queuing hours, number of stops, and so on).

5. TEST SITES

5.1 Introduction

The test sites are described in the following pages. Each site will be described according to these items: test site description, elemental TDM's and scenarios, data, modelling framework, results from modelling.
In particular, for each test site the list of the elemental TDM and the packages (scenarios) simulated can be found. Classification for TDM's has been described in chapter 2. Some scenarios present a list of measures which are not, in principle, TDM's: they are called "Long Term Measures" (LTM) and are those measures which may produce effects on travel demand in the far future (they include for example new infrastructures and telematics applications).
Most of the *packages* and measures simulated within the AIUTO test-sites can also be classified in *pushing* and *pulling* ones. "Pushing" refers to measures (or packages) mainly aimed to discourage the use of the private car mode (disincentive measures), while "pulling" means that the main aim is to encourage non-private modes (incentive measures). Test sites were also asked to model two "comparison scenarios", one with a strong, pure and non-discriminating pull measure (public transport free of charge) and one with a strong, pure and non-discriminating push measure (doubling of fuel price). These scenarios had to be used to compare elasticities of the used models.

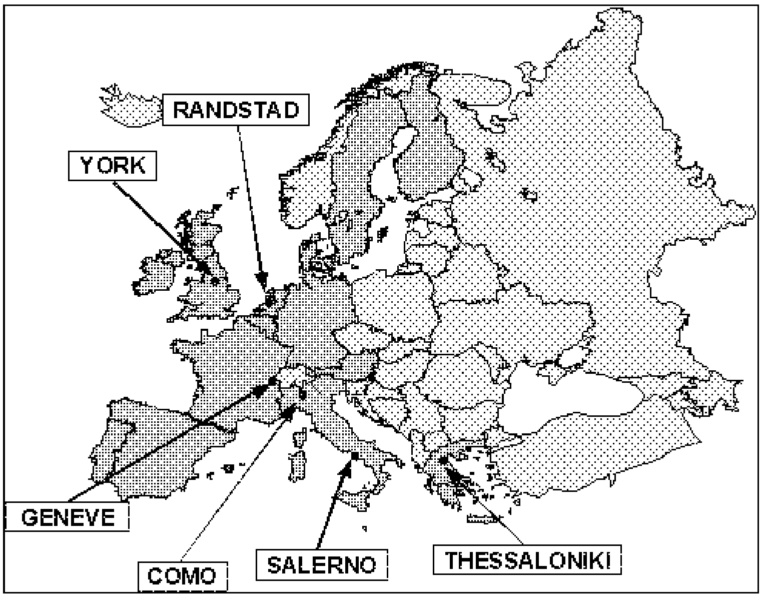


Fig. 16 - The six test sites

5.2 The Synthesis Tables

Some questions have been formulated to all the AIUTO partners about the procedures used during the evaluation phase and the simulated scenarios, to define some relevant topics and to compare the results of the local evaluation in all project sites[10]. All test-site replies are described in Tab. 17.

[10] The proposed questions were the following.

A common point for the AIUTO project can be found in the recommended use of an *evaluation matrix* in order to assess TDM measures' impacts.
All the AIUTO partners agreed that designing an evaluation matrix was a correct approach for an evaluation of the simulation results. As regards the practical way in which the evaluation is performed, the matrix can be analysed in a qualitative way or with a formalised procedure (e.g. with MAUT and sensitivity analysis): each partner was free to select the preferred way to do this.

Test-Site	**Q1 Minimum set**	**Q2 Comparison scenarios**	**Q3 Eval. proc.**	**Q4 Differ. Actors**	**Q5 Sensitiv. analysis**	**Q6 Innov. systems**	**Q7 D.4 frame**
Como	Yes	Yes	MCA	Yes	Yes	DaR CP	Yes (80%)
Salerno	Yes	Yes	No	No	No	(Yes) P&R	Yes
Randstad	Yes	Yes	Qual.	No	No	No	Yes
York	Yes	No	Qual.	No	Yes	(Yes) P&R	No
Geneva	Yes	Only 1	No	No	No	no	Yes
Thessaloniki	Yes	No	Qual.	No	Yes	No	Yes
	Alternative scenarios (TDM)	**Set of indic.**	**Hierarchy (levels)**	**Eval. matrix**	**Time disaggr. (periods)**	**Space disaggr. (areas)**	**Weights**
Como	1+11 (IS+PM)	~60	Yes (3)	Yes	Yes (2)	Yes (3)	Yes
Salerno	1+6 (IS+PM+RM)	~25	Yes (2)	Yes	No	Yes (3)	No
Randstad	1+9 (RM +CM)	~50	No	Yes	Yes (2)	No	No
York	1+4 (RM+CM)	~15 (+5)	No	Yes	No	Yes	No
Geneva	(1)+5 (RM+CM)	~30	No	Yes	Yes	No	No
Thessaloniki	1+10 (PM+RM+LTM)	~16	No	Yes	No	Yes	No

IS = Innovative Systems
PM = Pricing Measures
RM = Regulation Measures
CM = Complementary Measures
LTM = Long Term Measures (major road infrastructure)

Tab. 17 - Procedures and results from the local evaluation

- *Did you consider the minimum set of indicators? If not, explain why and in which way you have modified this minimum set.*
- *Did you consider the two "comparison scenarios" in your simulations? If not, explain why and in which way you think to provide information on elasticities.*
- *Which kind of evaluation did you use (e.g. Multi Criteria Analysis)?*
- *Did you consider different viewpoints (linked to different "actors" involved)?*
- *Did you consider a sensitivity analysis concerning data and weight attribution?*
- *Did you consider any subsystem (e.g. Dial-a-Ride system) to focus some particular innovative systems towards some user category?*
- *In Deliverable D.4 you can find a framework and a list of requirements. We would like the local evaluations to specify how their model systems achieve this framework or parts thereof, and how their analysis methodologies satisfy, fully or only partially, the listed requirements.*

5.3 Como (I)

5.3.1 Test Site Description

Como is one of the main historical towns in Lombardy Region, with a population of 84,000 (1995), 50,000 employees (about 2/3 are commuters) and 59,000 cars (1991). Recently Como has become a university town. The complex topography and the lake with the same name form constraint to the urban mobility system. The City of Como has a significant need to rationalise private transport in order to reduce traffic congestion and atmospheric pollution.
Como is connected to the motorway network, the Italian national railway (FS) and a local railway (FNM). Public transport in the city comprises buses, lake boats, and a cable-car.
Local and regional policy and strategies are related to the co-ordination and co-operation for land use and public transport and one of the objectives is to implement areas with traffic restraint as well as pricing measures for downtown and central areas (Convalle).

5.3.2 Scenarios

The elemental TDM's selected for Como were combined into the following scenarios.

S.1	Reference scenario	
S.2	PPIncreasing	Park pricing with a time dependent charge
S.3	RPFixed	Road Pricing with fixed toll
S.4	RPPeak	Road Pricing with peak hour toll
S.5	PP+TFI	Park pricing with a time dependent charge plus increase in public transport frequency
S.6	PP+DAR	Park pricing with a time dependent charge plus Dial-a-Ride
S.7	PP+CP	Park pricing with a time dependent charge plus car-pool
S.8	TFI	Increase in public transport frequency
S.9	DAR	Dial-a-Ride
S.10	FreeTransit	Public Transport free-of-charge (on interurban bus and railways too)
S.11	Doubleprice	Doubling of fuel price
S.12	SemiFreeTransit	Public transport free of charge (only urban network)

The above scenarios (excepted the reference one) can be classified into four groups, according to the kind of implemented measure and the level of evaluation:

– *in order to have a local evaluation on the kind of measures, in each test-site:*
  a) push (restrictive) measures (S.2, S.3, S.4),
  b) pull (incentive) measures (S.8, S.9),
  c) mixed measures (S.5, S.6, S.7),

– *in order to have an evaluation amongst the test-sites:*
  d) comparison scenarios measures (S.10, S.11, S12),

In the following, a description of each scenario is given.

Reference Scenario

S.1 The reference scenario represents the do-nothing situation. The only TDM measure applied is the actual restricted access area in the city centre. This area will not be modified, so it will be present in all scenarios and no change about it will be assessed.

Push Measures

The push modelling measures for Como aim to reduce congestion in the inner city during the peak hours of an average weekday, by using the following strategies: modification of the modal split, or the destination split or the time band of the trip. Car drivers will have a push to change mode, destination or departure time through the increase of the monetary cost of travel by private car (*pricing* measures)[11]. Simulation modelling will test the effectiveness of the pricing measures on the above strategies.
In the following the push measures scenarios are described. Simulations of these measures were carried out separately (measures are mutually exclusive).

S.2 *PPIncreasing*: Park pricing with a time dependent charge. All public parking spaces in the city centre are charged through the installation of parking meters. Three different zones are identified (Fig. 18).
The "red zone" is charged at a higher level than the "yellow zone". The base hypothesis is:

red zone	0.5 ECU for the first hour
yellow zone	1 ECU for the second hour 1.5 ECU for each of the successive hours 0.5 ECU for the first hour 0.5 ECU for the second hour 1 ECU for each of the successive hours

The third zone (central "green zone") is now a restricted access area with a large pedestrianisation, and it is thought to remain not accessible to drivers.
The base hypothesis has a cost-per-hour increasing with time, so as to encourage only short parking.
At the boundaries of the park pricing zones, three parking facilities with a lower charge are supposed to be realised *("subcentral parking")*. The charge will be 1.5 ECU for the whole day (1 ECU for a stay of 1 hour). Commuters coming from the North (including Switzerland), the South and the East and going to the city centre, can switch the parking destination using these low-charge parking facilities and reaching final destination on foot or by bus.
This measure is expected to supply mode and parking destination switches (for all trips) and final destination switch (only for discretionary trips). The time departure switch is not expected because there is no push to do this for car drivers.

S.3 *RPFixed*: Road Pricing with fixed toll. Car users will pay a fixed toll each time they cross a toll point (in downtown direction). The charge will be fixed (2 ECU for each entrance), not time dependent or distance dependent. Toll is applied during the whole day. Toll points are shown in Fig. 19.

S.4 *RPPeak*: Road Pricing with peak hour toll. Car users will pay a toll for each time they cross a toll point (in downtown direction). Toll will be applied only during morning peak hour 7.00 AM – 10.00 AM.

Both schemes of Road Pricing will provide mode and final destination switches (the destination switch is available only for discretionary trips, such as shopping purposes, not for commuters). The second scheme is useful to provide a departure time switch, because the toll acts as a push to advance or delay the departure time. There is no push to switch parking destination since parking charge are not simulated in these scenarios.

[11] All values will be expressed in ECU. The approximate rate is 1 ECU = 2000 Liras (Italian currency).

Pull Measures

The pull modelling measures for Como aim to test the effects of car usage caused by an improved supply. In particular, two measures were simulated: an increase in public transport frequency and a Dial-a-Ride scheme.

S.8 *TFI*: Increase in public transport frequency. A reduction of 50% of the average waiting time (from 5 to 2.5 minutes, only inside the Como city limits) is simulated.

S.9 *DAR*: Dial-a-Ride. A Dial-a-Ride scheme is simulated in Como and in its eastern neighbourhood. The base idea is a service with the same time of the car and cost equal to a double public transport fee.

Mixed Measures

The mixed modelling measures for Como aim to test the synergetic effects of implementing a mix of measures of both the push (park pricing) and pull type.

S.5 *PP+TFI* : Park pricing with a time dependent charge *plus* increase in public transport frequency. All public parking spaces in the city centre are charged through the installation of parking meters and three different zones are identified (as in scenario S.2). An increase in public transport frequency is simulated with a reduction of the waiting time (as in scenario S.8).

S.6 *PP+DAR* : Park pricing with a time dependent charge *plus* Dial-a-Ride. All public parking spaces in the city centre are charged through the installation of parking meters and three different zones are identified (as in scenario S.2). A Dial-a-Ride scheme is also simulated (as in scenario S.9).

S.7 *PP+CP* : Park pricing with a time dependent charge *plus* a car-pool. All public parking spaces in the city centre are charged through the installation of parking meters and three different zones are identified (as in scenario S.2). A car-pool scheme is simulated in the city centre. A pool team is composed of at least three persons. Poolers do not pay park pricing fees.

Comparison Scenarios Measures

These measures were defined in order to have two mutual scenarios in all test-sites: mutual scenarios should represent a common base analysis for conducting an evaluation of the elasticities of the models used in each test-site. The two comparison scenarios regard the hypothesis of public transport free-of-charge and of a doubling in fuel price. For Como, free-of-charge public transport has given rise to two slightly different scenarios. Comparison scenarios are not required to be realistic scenarios: they are only used for the purpose of testing the simulation modelling. They are as follows:

S.10 *FreeTransit*: Public transport free-of-charge, for the whole network considered in the case study.

S.11 *Doubleprice*: Doubling of fuel price. This scenario is based on a nation-wide doubling in fuel price.

S.12 *SemiFreeTransit*: Public transport free-of-charge, only in Como. It represents a less strong pull scenario, in which the free-of-charge applies only for the urban PT network of the City of Como.

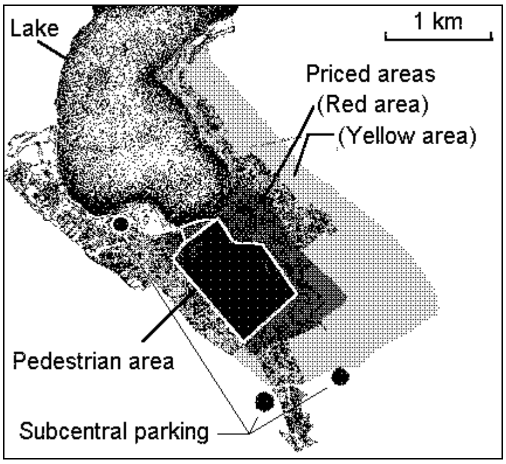


Fig. 18 - Park pricing scheme for the city centre

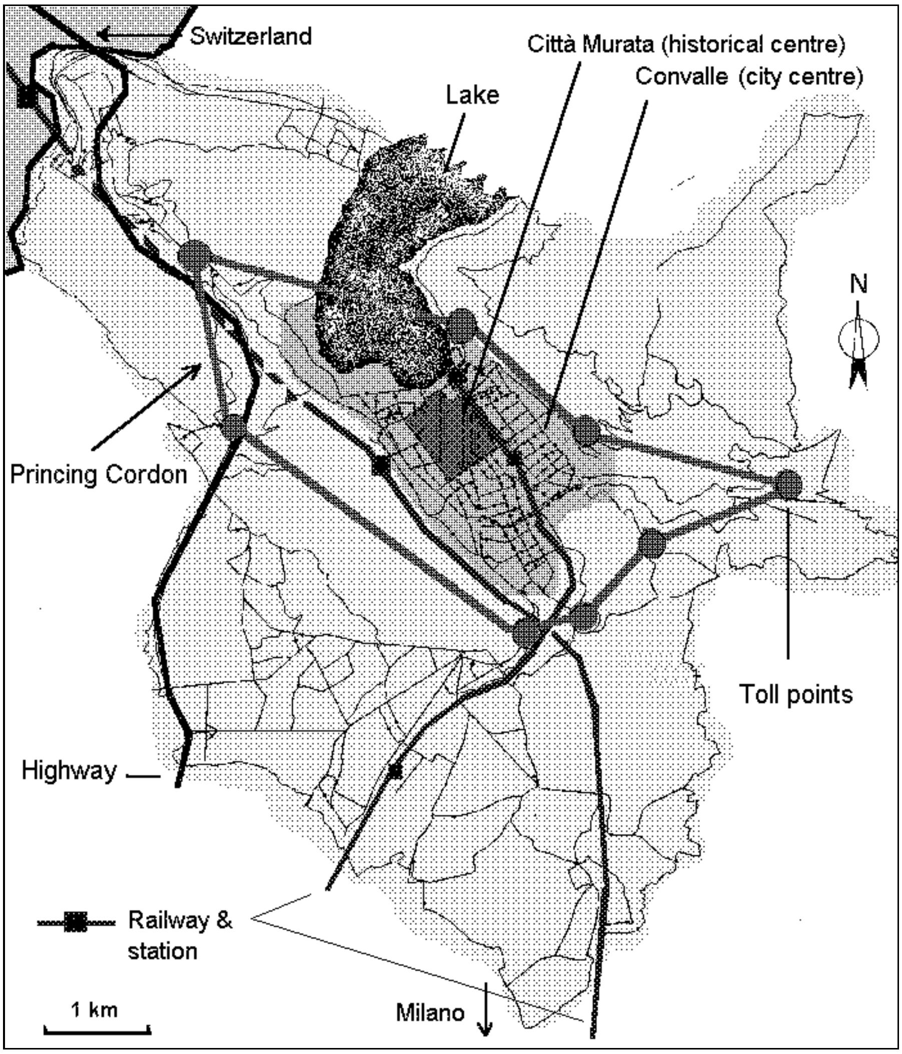


Fig. 19 - Cordon pricing toll points and network subdivision (the red area is the whole park pricing area).

5.3.3 Data

Demand data are represented by a set of OD vehicle matrices for the *morning peak hour (8.00-9.00 AM)* and for the *whole day (7.00 AM - 7.00 PM)*, segmented in different classes of users (commuters, business, other purposes), and in an SP data base gathered from a large survey carried out in 1995 in the city of Como. OD matrices were also estimated in 1995, updating by traffic counts a 1991 matrix. The territory within city limits has been subdivided into 57 zones, and other 17 zones represent the world around Como. In the following tables, data (absolute values) are reported.

	Total number of trips (cars)
Internal trips	5352
From Como to outside	5366
From outside to Como	5621
Crossing trips	1654
Total	**17993**

Tab. 20 - Total trips for the morning peak hour *(8.00-9.00 AM), from the OD matrix*

	Total number of trips (cars) – 12 hours	**Average number of trips (cars) per hour**
Internal trips	55502	4625
From Como to outside	56437	4703
From outside to Como	58989	4915
Crossing trips	17126	1428
Total	**188054**	**15671**

Tab. 21 - Total trips for the whole day *(7.00 AM - 7.00 PM). Data for the "average hour" are also shown*

The Stated Preference Data

SP data consist of 240 home interviews made to a set of car users previously sampled in order to fill the above mentioned OD matrices. The aim of such a survey was to assess the willingness of car users to change their travel behaviour. In particular 10 different SP experiments were carried out so as to take into account changes in mode choice (due to introduction of new transit or innovative modes), in destination choice and in departure time (in the case of peak hour road pricing). The sample uniformly covers three purposes, plus a set of trips crossing Como area. Five experiments (three for crossing trips) were asked to each interviewed person, as showed in the following table; experiment consisted of a set of binary choice games between car and another mode ("switching" preference).

Motivation	*Sample*	*PAY*	*ROUTE*	*POOL*	*DAR*	*BUS*	*TRAIN*	*BOAT*	*PARK*	*TIME*	*DEST*
Commuters-C	60	60		60		60	60			60	
Business-B	60	60			60			30	60	60	
Others-O	60	60			60			30	30	60	60
Crossing-CR	60	60	60							60	
TOTAL	**240**	**240**	**60**	**60**	**120**	**60**	**60**	**60**	**90**	**240**	**60**

Tab. 22 – Sample design for the SP survey.

According to the experiment, the variables considered are relative to travel time and waiting time, road pricing, park and transit fares, transit frequency, earlier and later arrival with respect to the desired arrival time.

Supply Data

Supply data are contained in a network built with the use of the geographical software *3G* (developed by MIP) and converted into the EMME/2 format. The network is not limited to the Como territory, but covers a great part of the Lombardy Region network. However, the resolution is far greater inside the city limits of Como.

The network has the following characteristics:

- 74 origin/destination zones;
- 984 links, each of them having the following information: link type, length, number of lanes, capacity, free flow speed, volume delay functions; moreover, for urban link types: gradient of the street, “disturbance” to the traffic, overtaking possibility;
- 290 nodes; most important junctions have the following information: type of regulation (traffic light or priority) and, in case of traffic light, cycle time and cycle length;
- cost functions (associated with the links) and penalty times (associated with the nodes and specified for each turning movement).

5.3.4 Modelling Framework

Modelling in Como can be subdivided in a *demand side* aiming to estimate the “switching effects” introduced by the TDM schemes starting from an actual OD car matrix, and an *assignment phase*, aiming to model the route choice effects. Mode change, destination change and departure time change are modelled using a unique framework. The model also provides the inputs to the evaluation scheme.

The modelling system is summarised in Fig. 23.

The black path is a complete one and it is referred to the peak hour situation. The double-lined path is referred to the “all day” situation (7.00 AM – 7.00 PM) reduced to a so called “average hour” to obtain results comparable with the peak hour. The double-lined path skips step 1 (Level Of Service attributes) as LOS varies during the day so that it is not possible to obtain “average” LOS attributes to be used as the basis for the switching model application. So the double-lined path is based on a strong hypothesis: “*the mode and the destination probability changes* per each OD pair and per each trip purpose *are the same in the peak hour and in the average hour*”. It is not realistic to apply this hypothesis to the departure time change, so the scenario “road pricing in the peak hour only” has not been modelled in the average hour situation.

In Fig. 23, the strong hypothesis is shown by means of the double-lined path avoiding step 2 (probability of changing/not changing) and using the peak hour probabilities as the input data to obtain the switched average hour OD matrix.

In the following the model system is explained step by step, with reference to the black complete path.

Step 1: the computing of the level of service attributes, necessary for the switching model, has been carried out by means of a *deterministic user equilibrium assignment*, using the present OD matrix. Monetary costs have been introduced in an hexogenous way.

Step 2: LOS attributes are the input for the switching model. This model estimates the probabilities to change from private car: such probabilities are estimated on each OD and for each trip purpose, and are used to obtain a new car OD matrix, assigned to the network in step 3. The new car matrix is obtained as the sum of a set of matrices: car drivers not changing their choice, car poolers, people changing destination.

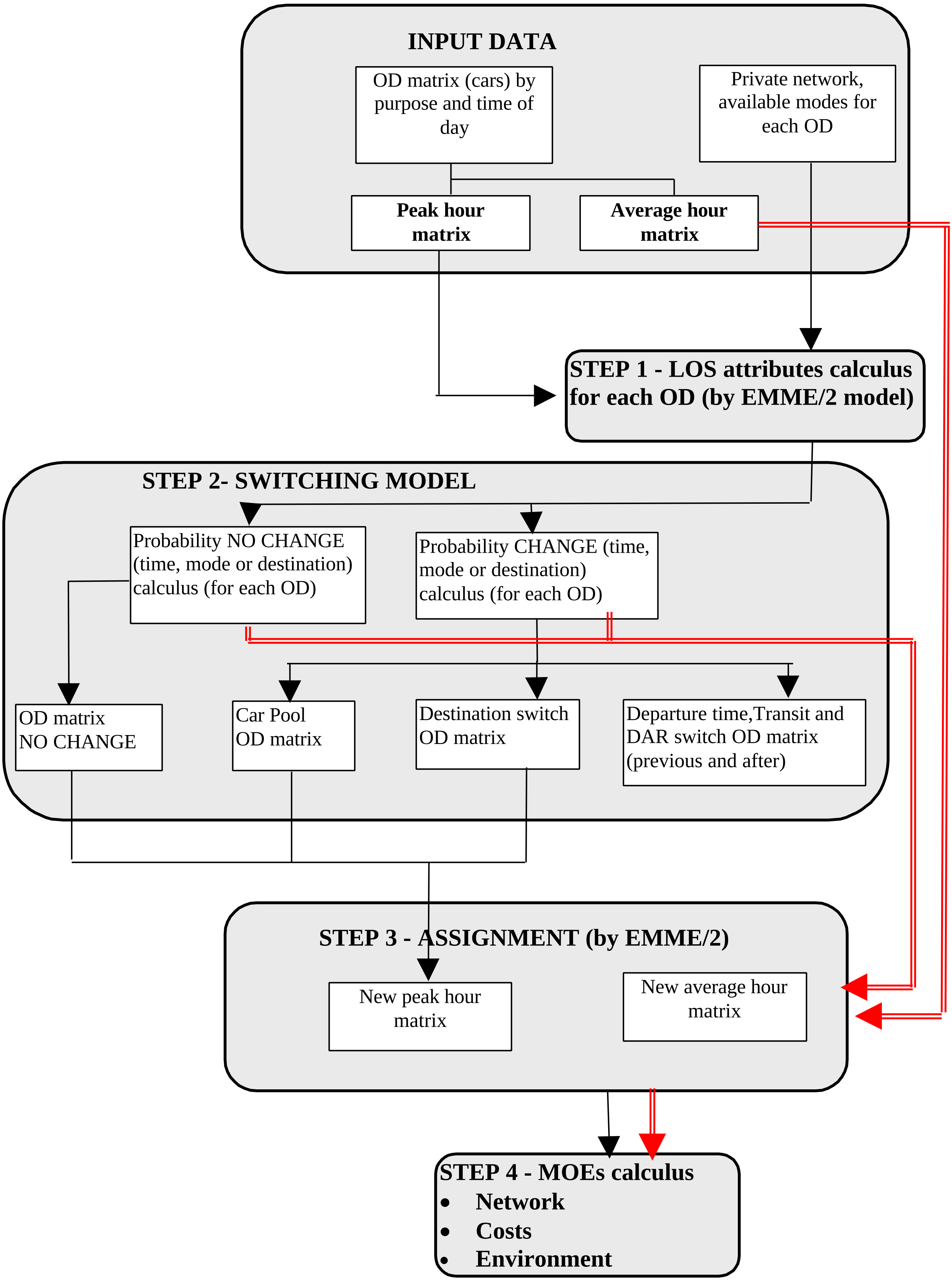


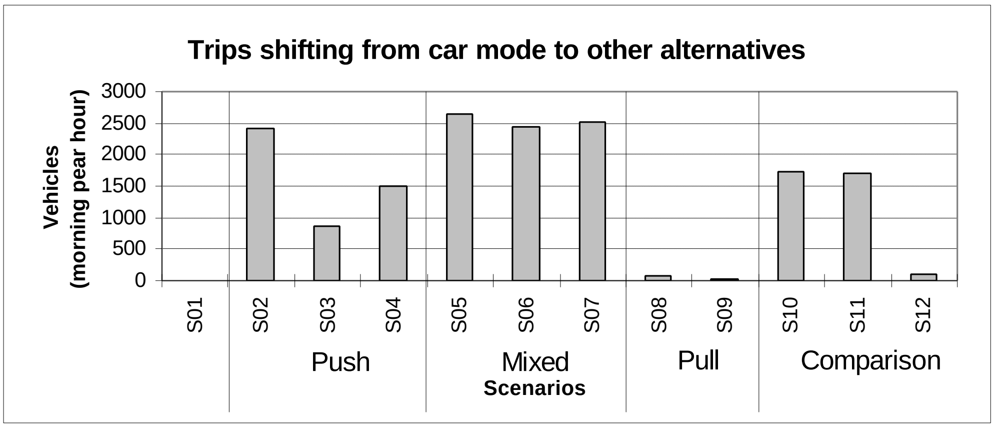
Fig. 23 - Modelling system description for Como

Step 3. The new car matrix is assigned to the network. The assignment provides the new flow pattern needed by the environmental models. This step provides LOS attributes which are generally different from those calculated in step 1. It could be possible to use them as new inputs to the switching model so as to iterate the cycle until a general equilibrium between supply and demand is reached. However this was not done because of the small difference between attributes in steps 1 and attributes in step 3, due to the fact that non-changing probabilities are generally high. The corresponding error is much lower than the general unexplained variance of the model.

Step 4. The flow patterns are used to calculate the MOEs. The MOEs have also been used in the evaluation scheme.

5.3.5 Results from modelling

As regards the modal shift, the Push measures reach significant switches (see for example the Park Pricing scenarios S02, S05, S06, S07, with 85-90% no change share, although some of the 10-15% switches represents a destination switch or a subcentral parking, not a true mode switch). The Pull measures, on the contrary, do not seem to be able to produce a significant car reduction (see scenarios S08 and S09, with less than 1% car reduction). In general the Peak hour demand is “destination constrained”, because at least the 75% of the trip purposes is “work” (this also causes the total switches in percentage to be very similar to the work trips figures). The destination switch is important (15%) for shopping trips when a Road Pricing policy is applied, and the subcentral parking places are able to capture work trips (10%) if a Park Pricing policy is applied in the city centre. Departure time switch is important for “other purposes” (discretionary trips). The demand for business trips is in general rigid.
Vehicle*km and Vehicle*hour decrease, but if in the Park Pricing scenarios such reduction is concentrated in the inner area, in the Road Pricing the decrease is spread out in the whole network.



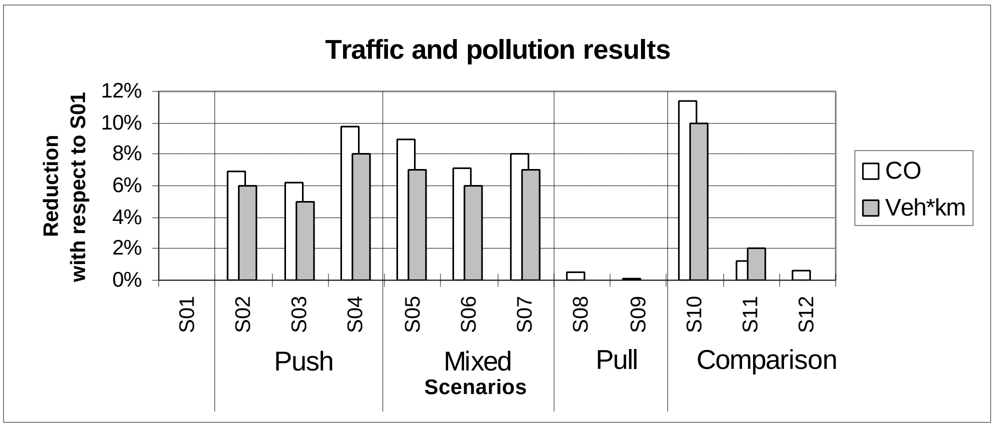
Tab. 24 - Modal switch results, morning peak hour, absolute values of shifts from car mode

		Push			Mixed		
	S01 Reference	S02 PP Increasing	S03 RP Fixed	S04 RP Peak	S05 PP + TFI	S06 PP + DAR	S07 PP + CP
No change	100.0%	86.5%	95.3%	91.6%	85.3%	86.4%	86.0%
Destination change	-	1.8%	2.2%	2.2%	1.7%	1.7%	1.7%
Transit	-	3.8%	2.5%	1.9%	6.1%	3.8%	2.7%
Dial-a-Ride	-	-	-	-	-	0.1%	-
Car Pool	-	-	-	-	-	-	4.0%
Subcentral parking	-	7.9%	-	-	6.9%	7.9%	5.5%
Departure time	-	-	-	4.3%	-	-	-

	Pull		Comparison		
	S08 TFI	S09 DAR	S10 FreeTransit	S11 Double price	S12 SemiFree Transit
No change	99.6%	99.9%	90.4%	90.5%	99.5%
Destination change	-	-	-	-	-
Transit	0.4%	-	9.6%	9.5%	0.5%
Dial-a-Ride	-	0.1%	-	-	-
Car Pool	-	-	-	-	-
Subcentral parking	-	-	-	-	-
Departure time	-	-	-	-	-

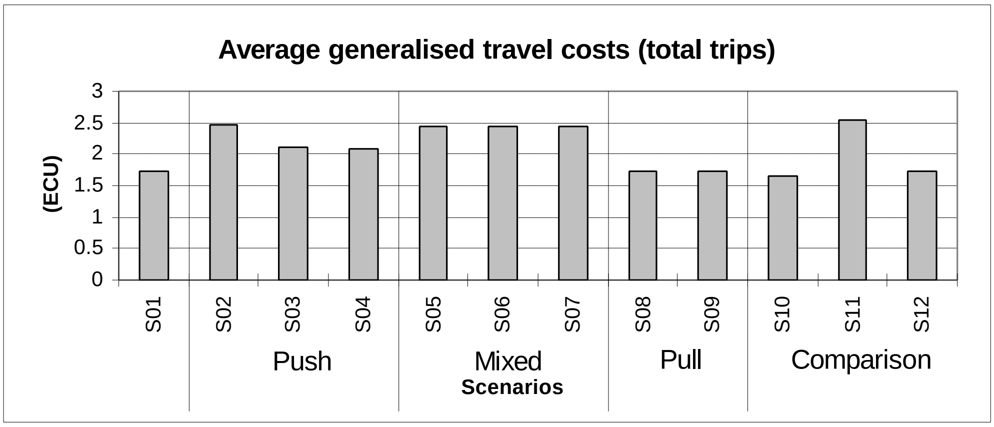
Tab. 25 - Modal switch results, morning peak hour, percentage shifts with respect to Reference.

As regards the economic indicators, the perceived travel cost increases when a pricing measure is applied: it means that the greater cost due to the pricing is not totally compensated by the saved time due to the speed increase. The Average cost is greater for Park Pricing than for the Road Pricing: it is an expected result because the road toll is lower than the parking charge (which is time dependent and can be very high for long stay).



*Tab. 26 - Vehicle*km results compared with reduction of CO emissions (percentage with respect to Reference)*

The environmental indicators have been calculated by using a CORINAIR model. The Push and the Mixed measures reduce the pollutant emissions and the fuel consumption. The reduction is approximately between 5% and 10%. Road Pricing have a “smooth” effectiveness because the reductions are spread out in the areas, Park Pricing reaches good results in the inner area but in the external area the situation is equal to the Reference scenario.



Tab. 27 - Economic results: global average generalised cost

The evaluation procedure for Como

Within the evaluation framework of the project, the results of Como test site were also used to perform an evaluation exercise, by means of a Multi Criteria Analysis (MCA) methodology.
Here only the key results are reported, derived from an evaluation matrix for the Como scenarios, containing all indicators of the "short list" previously presented on page 26 (see Colorni et al., 1998 for a complete description).
By means of a set of utility functions and of the weights shown in figure 28 (assigned in agreement with the transport officers of the Municipality of Como), a weighted sum has been found, leading to the final ranking of table 29. The evaluation was conducted without the three comparison scenarios (S10-12); that were included only for modelling purposes, were less realistic and thus were not suitable for an overall assessment of the performances (for instance it would have been very difficult to evaluate the cost of increased subsidies of S10 and S12, caused not only by the trips switched from car mode, considered by the model, but also by all trips already using PT mode).

Criteria	*1st level weights*	Indicators	*2nd level weights*	Weights
Network peak	*30%*	Veh*h	*50%*	15.0%
		Congested length[12]	*17%*	5.0%
		Speed	*33%*	10.0%
Network avg	*10%*	Veh*h	*50%*	5.0%
		Congested length	*17%*	1.7%
		Speed	*33%*	3.3%
Economical	*40%*	Gener. Avg travel cost	*30%*	12.0%
		1st equity	*5%*	2.0%
		2nd equity	*5%*	2.0%
		Investments	*20%*	8.0%
		Management	*40%*	16.0%
Environment	*20%*	CO	*33%*	6.7%
		NOx	*33%*	6.7%
		Fuel	*33%*	6.7%

Fig. 28 – The weights assumed in the evaluation process for Como (weights are the result of a joint elaboration of MIP and the officers of the City of Como)

The evaluation procedure has lead to the following outcomes.

- The ranking shows that **restrictive measures** have better results than **pull measures**: the incentives are not able to create a sensible car usage reduction (the reduction of the waiting

[12] For each link the flow/capacity ratio was computed, the links where said ratio exceeded 0.9 were selected and the "congested length" was the sum of their lengths.

times, in an urban context, brings very modest time saving, so that the "pull" aspect is very weak). On the contrary they have high investments costs (increasing the public transport frequency means in fact buying new buses).

- The latter consideration gives an explanation to the fact that incentive measures give worst performance than the Reference scenario (mainly the TFI, because the DAR performance is extremely close to Reference).

Scenarios	Weighted sum	Ranking
S03 – RPFIXED	0.620	1
S04 – RPPEAK	0.469	2
S06 – PP+DAR	0.442	3
S02 – PPINCREASING	0.439	4
S07 – PP+CP	0.426	5
S01 – REFERENCE SCENARIO	0.406	6
S05 – PP+TFI	0.405	7
S09 – DAR	0.404	8
S08 – TFI	0.345	9

Fig. 29 – The final ranking

- **Road Pricing** gives a better performance than **Park Pricing**. Much more revenues can be collected by the Road Pricing techniques (in the presence of similar results in car reduction), and the travel cost is lower for Road Pricing. Road Pricing, in fact, involves a greater number of car drivers, so that similar revenues can be collected with lower individual charging. It should also be noted that the evaluation has been made considering the urban area altogether: a specific attention to the inner area (where park pricing positive effects take place) may lead Park Pricing to better results.
- The good results of Road pricing (and in particular of the best ranked scenario RPFixed) are confirmed by a *sensitivity analysis* conducted on the vector of weights.
- The synergetic "Push and Pull" effects (**mixed measures**) are not so great, as a consequence of the low results of the "Pull" part of the measures.
- *Implementation and operating costs* appear as a key aspect in the evaluation matrix, as they have a high weight and often ask for relevant financial resources. In this exercise an effort was made to include all costs that should be borne by the Local Authority in order to implement the measure (including indirect costs, e.g. improvement of public transport services, in order to accommodate people switching from private car).

5.4 Salerno (I)

5.4.1 Test Site Description

Salerno is a typical Italian medium-size city on the Tyrrhenian Sea, not far from Naples. The town lies at the centre of the Gulf, at the mouth of the Irno River valley, near the Piana del Sele towards which it is rapidly expanding.
The city extends for about 60 km^2 with a narrow and long area along the Gulf of the same name, because of the presence of the mountains behind the coast. Salerno is structured in three distinct centres: the medieval part, on the slopes behind the coast, characterised by narrow winding streets, the eighteenth century area beyond the old walls, and the modern town, built after World War II, mainly towards the South, often in a haphazard sprawl.
Three motorways meet at the west side of the city and an urban beltway skirts the town, with 5 main ramps for town traffic. A direct ramp connects the port of Salerno to the motorways. Salerno is also crossed by the Naples-Reggio Calabria railway and is connected to the University and the northern area by local railway.
Salerno's economy, facilitated by the lines of communication, is based on the marketing of provincial agricultural products, on maritime activities and on banking. Industry has developed in the food, engineering, textiles and ceramics sectors. There is a high proportion of tourist trade.
The inhabitants are 160,000, with a density of about 2,667 inhabitants per square km. In Salerno the main source of employment is represented by the public or private services (about 70%) while industry absorbs less (about 26%).
The city suffers from heavy traffic problems, due to a crowded, densely built centre, limited parking space, high mobility demand with large variability.
With a particular reference to parking problems the surveys made during 1993 highlighted a strong influence of the illegal parking that evidences an imbalance between demand and supply and a too weak regulation. In fact in the central area the gathered parking capacity is as follows: 4870 free, 811 charged on street, 798 parking disc, 3174 charged off street and 3538 illegal parking spaces.
The Salerno area (Fig. 31) has been subdivided into 53 internal traffic zones, taking into account the land-use, the inhabitants density and the connections to the private and the public transport systems. The interaction between the city and the external area has been simulated with 9 external centroids which represent the exchanging movements of people entering the city and exiting from it. Those centroids are individuated by the intersection between the imaginary cordon line delimiting the study area and the main traffic streams.

5.4.2 Scenarios

With respect to the TDM elementary measures described in chapter 2, five TDM packages have been built and simulated in the Salerno test-site. Table 30 gives a global view of the TDM packages with respect to the TDM measures involved in them. It is important to notice that the table highlights a classification of the packages depending on their purpose towards the transport mode: packages 1 and 2 are based on measures that "push" the private mode, while package 3 "pulls" non-private modes.

		TDM PACKAGES				
TDM measure	**Type**	**0**	**1**	**2**	**3**	**4**
Park Pricing	PUSH	-	Y	Y	-	Y
Parking Management	PUSH	-	Y	Y	-	Y
RAA	PUSH	N	N	Y	N	Y
Park & Ride	PULL	N	N	N	Y	Y
Public Transport enhancement	PULL	-	-	-	Y	Y
Type of package		base	PUSH	PUSH	PULL	MIXED

Tab. 30 - TDM packages proposed in Salerno

The following figure represents the TDM packages in the city.

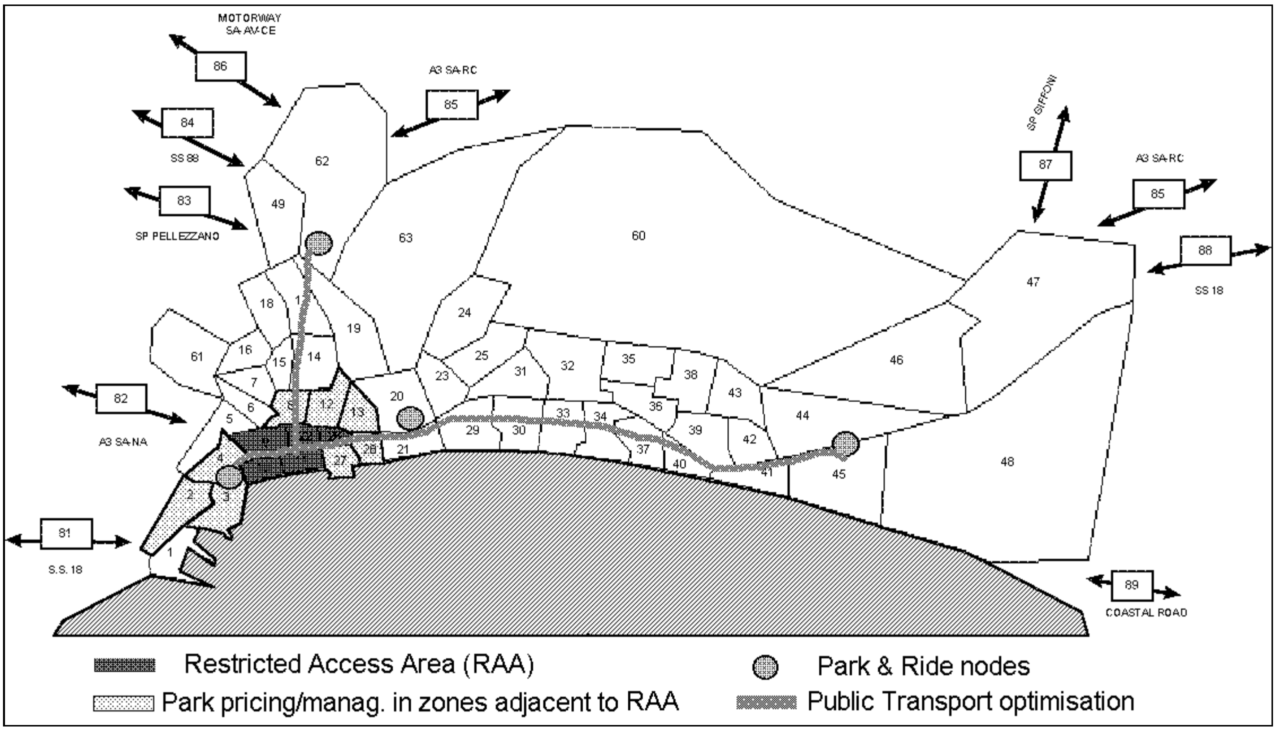


Fig. 31 - Salerno: urban traffic zones and main traffic streams

In more detail, the proposed packages can be described as follows:

<u>Package 0 - Base</u>

Is the base package referring to the traffic state in Salerno in 1993, when no Park & Ride and Restricted Access Area measures were applied.

Therefore the simulation takes into account the supply situation of 1993. The parking situation too is referred to the 1993 surveys, and is characterised by five different fares structures depending on the parking duration and on the user category and three classes of fines to control the illegal parking.

<u>Package I - Parking pricing and management</u>

Aim of the package is to test the effects of sole parking policies. The measure has been applied to the parking supply in the central area of Salerno by the introduction of a parking pricing and a parking management policy. The application of the package allows the access and the circulation in the very central area even though the strong reduction of free parking towards charged and disc parking and a better control of the illegal parking leads to disincentive or "push" the private transport mode.

Package II - Restricted Access Area

The package comprises the same Parking measures of package I but takes into account the introduction of a Restricted Access Area measure. With respect to the previous package described, this package stresses more the aim to "push" the private mode.

Package III - Park & Ride

Adopting this package has the purpose to incentive (or "pull") the use of the non-private transport modes. In fact the package consists of the simulation of a Park & Ride scheme and a consequent reorganisation of the Public transport.

Package IV - Complete

The package is considered complete because it involves the simulation of all the TDM measures proposed for Salerno: this is the reason why it has been also defined as "mixed" package, since it «mixes» both push and pull aspects.

Two further packages have been simulated in order to test the elasticity of the models. They start from the base package situation and consider two hypothetical comparison situations:

Package V - Public Transport fare

Public transport completely free of charge.

Package VI - Fuel pricing

Doubling of the fuel price.

5.4.3 Data

Socio-Economic Data

The *socio-economic and demographic data* come both from the population and industry census made by the National Institute of Statistic (ISTAT) during 1991 and from surveys made in the same year by ELASIS in collaboration with the CSST.

Supply Data

Networks data were collected analysing the physical and functional features of the transport network. In particular data come from the cartography and from surveys made in different time bands. The supply has been drawn in two separate networks for private and transit mode, which are coded in a MT.MODEL database.

The private network has been classified depending on roads functional levels and it consists of 526 nodes and 1147 links. For each link the geometrical, territorial and functional features have been gathered both from the cartography and from surveys made in different time bands.

Referring to the transit system, the supply is represented by two modes: bus and train. The internal service of the city is carried out essentially by the ATACS company with a marginal contribution of the urban stretch of the railway. The extra-urban public service is equally performed by the train and bus modes, which is mainly managed by the SITA company that connects the city of Salerno to the closest destinations. With reference to the train mode, Salerno is served by the important railway Naples - Reggio Calabria and by the secondary line M.S. Severino - Avellino (both under the FS management). The transit network has been generated analysing the urban and sub-urban bus lines and adding to these the railway connections and the pedestrian links. The coded network consists of 687 nodes (bus stops, stations, terminus) and 1940 links. A survey has been conducted, for different time bands, to describe the features of the bus lines and the following information have been collected: frequency, number of passages, travel time terminus to terminus, commercial speed, technical characteristics of the transit vehicles (e.g. seats).

Demand Data

The *Travel Demand data* available were collected by means of RP surveys conducted during 1991 by ELASIS in collaboration with CSST. They are related mainly to the urban area of Salerno which

has been subdivided into 53 internal zones and 12 external zones. The investigations have been performed both for the private and for the public transport system and they consist of demand surveys and counts.
The demand surveys, collected by on-board interviews to private and public passengers and by telephonic interviews, generated a set of OD matrices characterised per trip purpose, mode and time band.
The counts data consist of counts of private vehicles flows on internal and cordon sections, counts of buses and train flows, counts of passengers on buses and trains.

Parking Data

Data concerning both the parking supply and the demand have been gathered by surveys made during 1993.
Aim of the supply survey was to determine the main parking features, as for example the number of parking spaces, fares, time limitations, etc. For that reason 7 categories of parking have been individuated:

a. on street - free parking
b. on street - charged parking
c. on street - parking with limitation in time
d. on street - illegal parking
e. on/off street - parking reserved in destination
f. off street - box for residents
g. on/off street - multi-storey parking and garage

A parking demand survey has been carried out in different time bands of working days for all the parking categories in order to individuate mainly the occupancy and the duration of the parking.

5.4.4 Modelling Framework

With respect to the possible modelling framework reported in chapter 4, the overall modelling system used in the Salerno test-site is shown in the following figure.

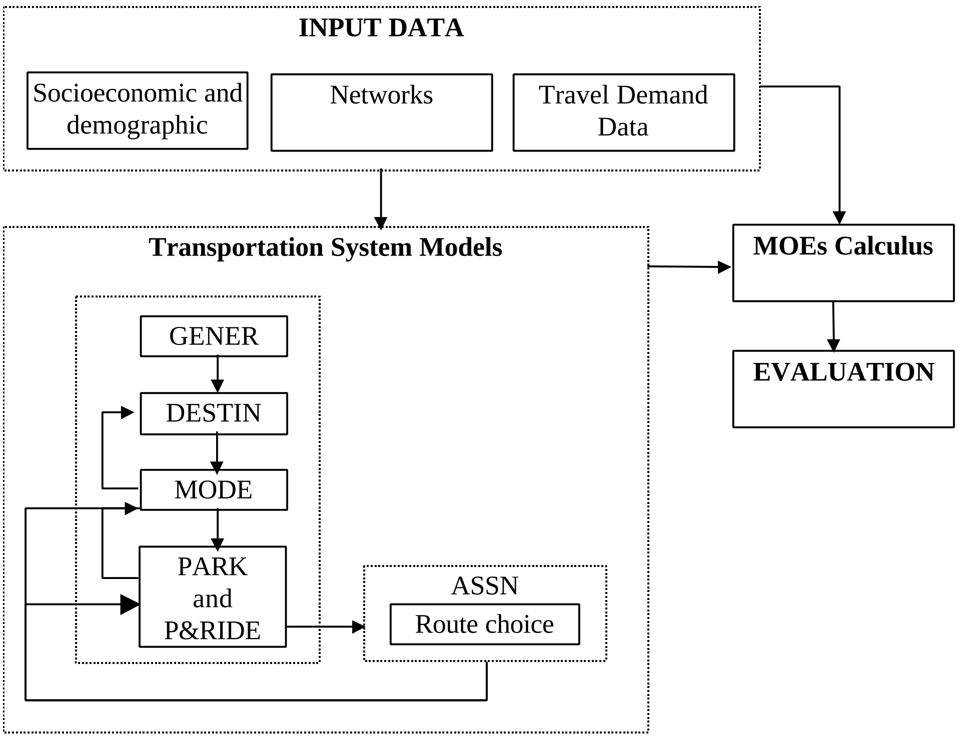


Fig. 32 – Modelling framework.

The main differences among the two architectures consist of the lack of any time-dependent model (nor activity time nor departure time models); moreover, two specific sub-models have been explicitly added: one related to Parking (type and location) and the other related to Park&Ride (intermodal node) choices. The overall system of models approaches the demand elasticity through an external equilibrium approach, up to the distribution sub-model.
The departure time model has not been introduced in the overall framework due to lack in proper and “safe” data, needed for the calibration of such a model. In practice, the type of TDM measures applied to the Salerno test-site are time independent, since they are applied on the whole day without any time differentiation. However, different levels of congestion (both on the network and in the parking spaces), indirectly induced by TDM measures, could change the travel utilities (with respect to the reference scenario) among different time periods. Thus, from a rigorous point of view an activity time switching could ensure a more rigorous modelling approach.
The only time period modelled in the Salerno test-site is the a.m. peak period. Such a choice has been motivated by the lack of proper and “safe” data for the calibration of the overall modelling system for other periods. Thus, some of the TDM measures impacts could be overestimated, if straightway extended from the simulated a.m. peak to the whole day, both because the relationship between demand and MOE’s is strongly non-linear and the distribution among trip purposes is quite different for different time periods of the day. In Tab. 33 the percentage distribution of the trip purposes within the a.m. peak is presented, as well as the average trip purposes distribution within the whole day.
Different trip purposes are distinguished simulated not only by different demand models but also by different duration of the parking at the end of the trip, which mainly influence the parking choice model.

	A.M. Peak	Whole day
WORKPLACE	43%	20%
OTHER CONSTRAINED	26%	28%
UNCONSTRAINED	18%	48%
EDUCATIONAL	13%	4%
TOTAL	100%	100%

Tab. 33 – Trip purpose distribution

Our feeling is that, for the whole day:

- the impacts due to the Restricted Access Area should be moderated, since the residents in the RAA can circulate when “coming back home”;
- the impacts due to Parking policies should be moderated, since residents coming back home mostly use reserved parking places, and because charging and limitation are generally not extended to night hours; furthermore the duration of stay (in our model related to the trip purposes) for the trips of the whole day is less “in average” than for the a.m. peak;
- the impacts due to Park&Ride should be stable on the whole day.

<u>Summarising:</u>

- in the used modelling framework, the policies tested in Salerno influence: primary destination choices, mode choice, parking type and location choices (for private modes), Park & Ride node choice;
- the policies tested in Salerno could also influence the time period choice; however, such a choice level is not covered;
- considered travel purposes are: work, other “destination constrained” trips, other “destination unconstrained” trips, educational;
- demand segments are also distinguished per age (which directly impacts on mode choices) and duration of the parking at the end of the trip (which directly impacts on the parking choices);

- the modes being distinguished in the model system are: car (driver and/or passenger), bus, motorbike, pedestrian, mixed modes (Park and Ride);
- a.m. peak in an average working day period is modelled.

The parking model (which is a non-standard component of traditional modelling architecture) can be summarised in the following:

- parking choices are modelled through a Logit-type non-network approach;
- considered attributes (within a Logit-type model) are:
  - time spent searching an available parking space, *b_search*;
  - monetary cost, that is fare cost related to parking infrastructure and monetary risk for illegal staying or overstaying, *b_money*;
  - time spent walking from the parking infrastructure to the destination (which could be in a traffic zone different from the parking one), *b_walk*;
- parking choices are "congested", which results in:
  - equilibrium within the parking model;
  - elasticity of the overall demand modelling system.

The beta's of each of those attributes are shown in the following table (in case of time expressed in hours and money expressed in ITL*1000):

	WORK	***OTHER CONSTRAINED***	***OTHER UNCONSTRAINED***
b_search	-5.175	-9.869	-9.869
b_money	-0.974	-1.386	-2.615
b_walk	-8.065	-20.712	-21.28

Tab. 34: Parameters of the Parking model

The mode choice model concerns 5 modes: car (driver and/or passenger), bus, motorbike, pedestrian and mixed mode (P&R).
Mode choice attributes are:

- time spent on board (for car, bus and motorbike), *b_time*;
- money spent for travelling (excluding parking costs, for car, bus and motorbike), *b_money*;
- generalised parking cost (represented by the logsum of the parking model), *b_lsum*;
- pedestrian time (for bus and pedestrian), *t_ped*;
- waiting time (for bus), *t_wait*;
- auto specific modal variable (for car), MOD_AUTO;
- pedestrian specific modal variable (for pedestrian), *MOD_PED*;
- motorbike specific modal variable (for motorbike), *MOD_MOTO*;
- age specific variable (for motorbike, it takes 1 if the user's age is less than 30, 0 otherwise), *AGE_MOTO*.

The values of the related beta's (time in hours and money in Lit*1000) are listed in the following table:

	WORK	OTHER CONSTRAINED	OTHER UNCONSTRAINED
b_time	-1.863 (-4.451)	-1.961 (-5.340)	-3.118 (-3.806)
b_money	-0.3508 (-4.012)	-0.2754 (-4.367)	-0.5197 (-3.219)
b_lsum	0.3599 (+3.064)	0.1987 (+2.528)	0.02033 (1.984)
t_ped	-2.9063 (-3.986)	-4.3142 (-4.154)	-4.4276 (-2.939)
t_wait	-4.0241 (-3.428)	-4.9025 (-3.865)	-6.1425 (-2.846)
MOD_MOTO	-1.563 (-3.372)	-1.6310 (-2.604)	-2.2350 (-2.088)
AGE_MOTO	2.0820 (+2.988)	2.3310 (+3.377)	2.6940 (+2.393)
MOD_AUTO	0.8340 (+2.967)	0.9210 (+2.885)	0.8260 (+4.362)
MOD_PED	2.1970 (+7.449)	3.127 (+12.224)	2.6980 (+8.631)
r-sq	0.39	0.46	0.52
Sample Reconstitution	82%	83%	86%
Sum of prob of chosen	73%	76%	80%

Tab. 35: Parameters of the Mode Choice model (t_ratios between brackets)

The distribution model is a Logit with three attributes:

- inclusive variable of the mode choice model, *b_lsum*;
- variable which takes into account if the origin and the destination zones are the same, *b_local*;
- attraction variable of the destination zone, *b_Attr*.

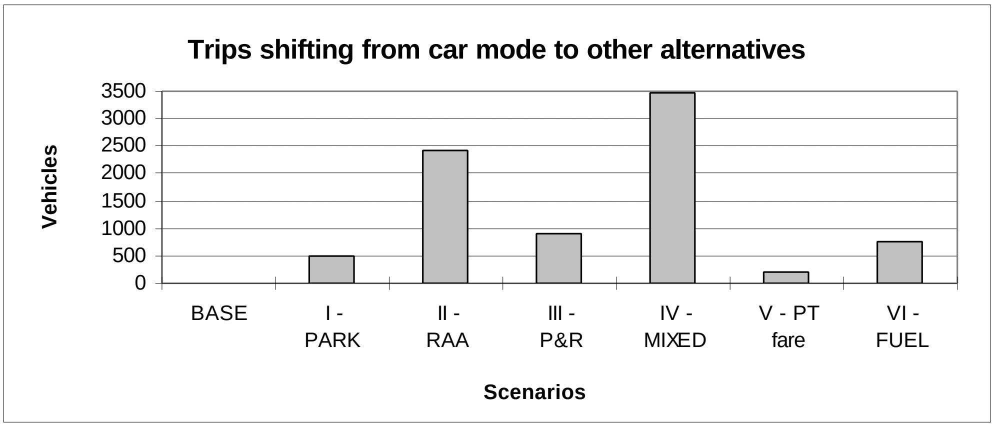
The systematic utility expression of the distribution model is:
$V(d/o) = b\_lsum * Lsum\_mod_{od} + b\_local * Local_{od} + b\_attr * Attr_{d}$
The values of the related beta's are described in the following table:

	EDUCATIONAL	WORK	OTHER CONSTRAINED	OTHER UNCONSTRAINED
b_lsum	0.9793 (6.0097)	0.2403 (4.4145)	0.3490 (7.2224)	0.8380 (9.2289)
b_local	0.5859 (0.7001)	0.2687 (0.6979)	0.4146 (0.6970)	0.2073 (0.3413)
b_Attr	0.7110 (21.4054)	0.7377 (17.3354)	0.7802 (13.2309)	1.0111 (18.4223)

Tab. 36: Parameters of the Distribution model (t_ratios between brackets)

5.4.5 Results from Modelling

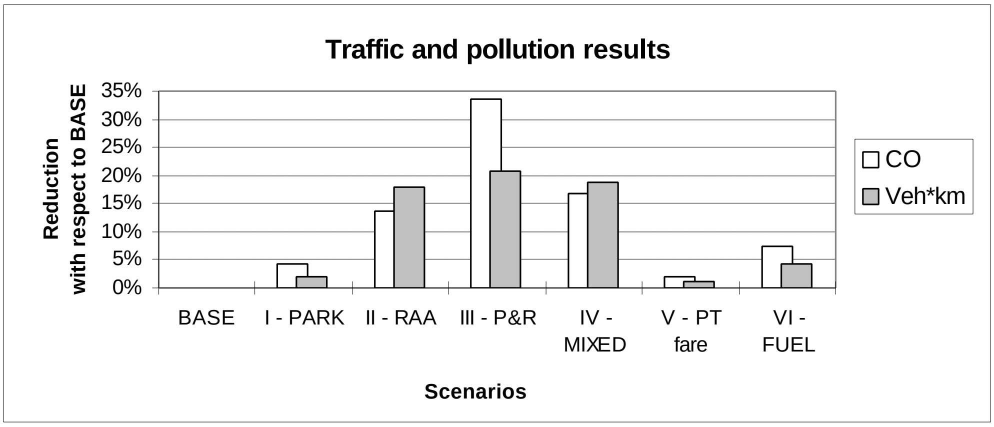
Results from simulations are shown in the following table and charts.
As expected, all packages reduce private traffic in favour of the public transportation modes. Such a reduction is much more sensible in case of packages 2 and 4, when a traffic limitation policy is directly applied. The reduction is less evident for package 3, when a Park & Ride approach is applied. So if the objective of the packages is simply to decrease private traffic, the most effective TDM packages seem to be the second and the fourth.



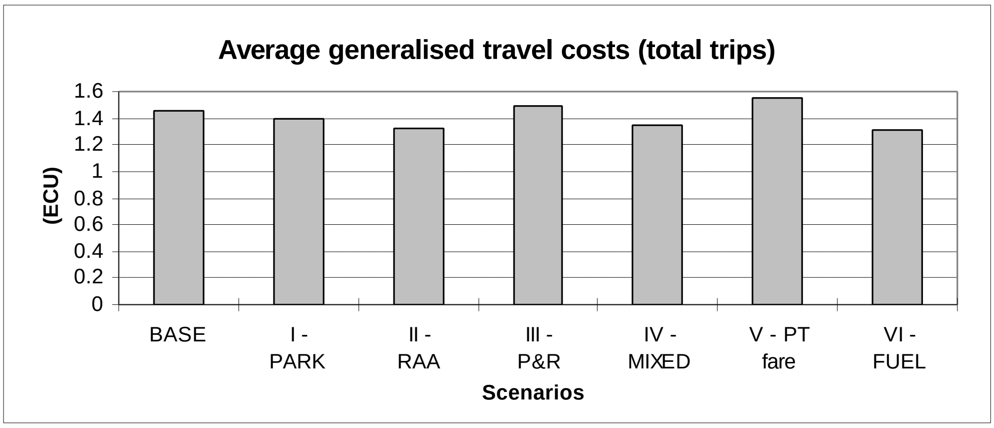
Tab. 37 - Modal switch results, morning peak hour, absolute values of shifts from car mode

Scenario	BASE	I - PARK	II - RAA	III - P&R	IV - MIXED	V - PT fare	VI - FUEL
Car trips	-	-3.00%	-14.90%	-5.60%	-21.40%	-1.20%	-4.70%
Bus trips	-	+5.90%	+37.20%	-1.90%	+15.60%	+35.10%	+10.20%
Motorcycle trips	-	+0.70%	+23.70%	-3.80%	+16.70%	-13.80%	-2.10%
Pedestrian trips	-	+3.30%	+8.20%	-1.90%	+7.10%	-6.90%	+5.60%
P&R trips	-	-	-	(+100%)	(+100%)	-	-

Tab. 38 - Modal switch results, morning peak hour, percentage shifts with respect to Reference



*Tab. 39 - Vehicle*km results compared with reduction of CO emissions (percentage with respect to Reference)*



Tab. 40 - Economic results: global average generalised cost

The results confirm that both proper simulation models and MOEs have to be used in order to assess TDM measures impacts. In fact the apparently counterintuitive result is obtained that even if the Restricted Access Area scenario gives the most significant reduction in car use, this leads to an increase of pollution indicators. This is due by the increasing of the total kilometrage, since most of users still using car make larger tours around the restricted zone to reach their destination. Better results are obtained by scenarios based upon pricing, where there is an effective reduction of the total vehicle*km. Such a reduction is also relevant in the cordon-based Park-and-Ride scenario, where a relatively small car-use reduction corresponds to a much larger reduction of kilometrage.
Parking policies also induces some other relevant modifications of the travel demand pattern. On one hand the increased parking prices and limitations discourage *long-stay* trips from using parking facilities in the city centre, on the other hand the resulting increase of parking lots' availability encourages *short-stay* trips in using the same parking facilities. Such an increased turnover leads to a more effective use of the available parking supply.

5.5 Randstad (NL)

5.5.1 Test Site Description

The Randstad is an urban agglomeration in the western part of the Netherlands. Its population is around 6 million, including 8 large cities. The Randstad has no strictly defined administrative political boundaries. In the current study, (parts of) the provinces of Utrecht, Noord-Holland and Zuid-Holland are defined as the Randstad. The following figure shows the Randstad region as used here.

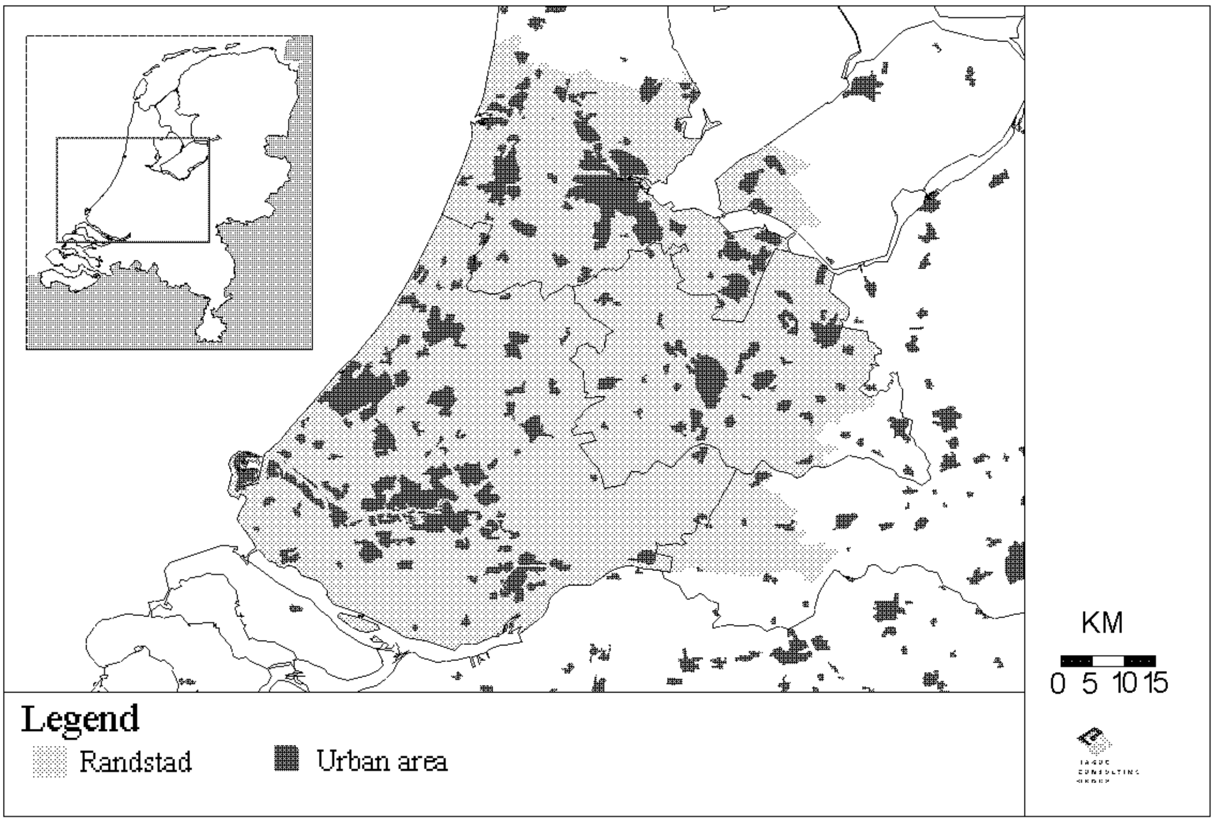


Fig. 41 –The Randstad region

The following table presents information on the key characteristics of the Randstad area, in terms of socio-economic data, numbers of passenger cars and surface area.

Characteristic	Value
Number of inhabitants	6.07 mln
Number of households	2.60 mln
Number of employees	2.17 mln
Number of jobs	2.45 mln
Number of cars	1.98 mln
Surface area	5910 km^2
Density	>1000 / km^2

Tab. 42 - Randstad essential characteristics.

The Randstad is an urban system that consists of eight cities with more than 100,000 inhabitants. Of these cities, Amsterdam (700,000), Rotterdam (600,000), The Hague (450,000) and Utrecht (250,000) are the larger ones. All cities are situated in a ring around a less dense populated, agricultural area, called the Green Heart. The diameter of this area is approximately 50 km in all directions.

Because of the dense urban system of the Randstad, the area suffers substantial traffic and transport problems, both for private and public transportation. Congestion is a recurring problem in both morning and evening peak periods, and increasingly also during the off-peak periods. Congestion occurs both on urban and interurban highways and on other roads. The rail and bus networks in the Randstad suffer congestion problems particularly during the peak periods.

On national, regional and local level, efforts are being made to improve current and future problems in the transport area. The general framework is that of the National Transport Structure Plan of 1989. Objectives include the reduction of congestion, doubling the number of passengers in public transport and the implementation of user charges. On a local level, policies often aim to restrict available parking capacity, increase parking charges and to improve compatibility between land use and accessibility.

5.5.2 Scenarios

In the AIUTO-Randstad project, TDM measures are the various elements that form a TDM package. These TDM measures are classified in three main groups; '**B**'*uild* options for new highways and lanes (strictly non-TDM but seen as a possibly necessary additional measure) , '**C**'*ontrol* measures to manage highways, and '**D**'*eterrent* measures to car-use. They act in addition to an '**A**'*bsolute* base scenario, creating an **A**, **B**, **C**, **D** grouping of policies and input assumptions for the models.

The 'B'uild measures include:

B1 : Lane Control and New Highways
In the category Build measures, the effects of implementation of major new infrastructure are analysed. New highways are built and lanes are added to various existing highways, thus improving the accessibility of the region.

The 'C'ontrol measures include:

C1 Access control

In the implementation of access control management measures, the access to parts of the road network is restricted to certain users that can be identified in a visual or any other form. For the current work, access control TDM measures are implemented for freight traffic and certain groups of users willing to pay for congestion free travel.
The effect of lanes restricted to freight use are implemented in the model by adding freight-only lanes with a capacity of 1500 pcu/hr at some locations in the Randstad region.
For target groups of users (visually distinguishable), another method is implemented. These user-group- and/or pay-lanes are implemented as general available capacity increases of 800 pcu/hr at certain locations in the region.

C2 Traffic Calming

Traffic calming measures are designed to make traffic run more smoothly, thus improving the flow and the reliability of road traffic. Hence increasing highway capacity and avoiding the negative impacts related to the environment and safety.
Two types of Traffic Calming measures are implemented on some locations on the highways: a maximum-speed reduction and an overtaking ban for freight.
Firstly, around the major cities in the Randstad region, a maximum-speed reduction is implemented at various locations on the highways. The effect of this measure is a better flow of traffic, which is implemented in the model system as an increase in the capacity of 1% at the selected locations where the measure is implemented.
Secondly, implementing an overtaking ban for freight on certain parts of the highways will also lead to an increase of highway capacity and an improvement of the quality of the flow of traffic. Probability of congestion will be lower and the length of the congestion queues will be reduced. Further, the probability of accidents will be lower, thus reducing incidental congestion as well.

C3 HOV priority

High Occupancy Vehicle measures are related to the exclusive use of lanes by one or more identified user groups. In doing so, the scarce road space can be used more effectively, thus increasing the capacity and reducing the congestion probabilities for road traffic.
In the Randstad context, these measures deal with the use of with-flow bus lanes by freight and other specific user groups. The use of bus lanes by freight is implemented in the model system as lanes with a capacity of 1500 pcu/hr that are not available for other traffic than freight (and bus, of course). The use of bus lanes by other user groups is implemented as a capacity increase of 800 pcu/hr which are available to all users.

C4 Variable Message signs

Variable Message Signs provide drivers with up-to-date travel information regarding traffic conditions on the highways. In The Netherlands, these signs are implemented under the name DRIPS (Dynamic Route Information Panels), which provide various sorts of information to the car driver on highways. This includes information such as expected travel time (including wait time due to congestion) and length of queues to a next point, but also information on travel time and queues for alternative routes at decision points in the network so that alternative less congested routes (e.g. on ring roads) can be chosen.
The effect of the DRIPS is implemented in the model system as a capacity increase of 1% on all highways in the Randstad region.

The 'D'eterrent measures to car-travel include:

D1 Road Pricing

In the AIUTO simulations, Road Pricing is envisaged as a fully automated electronic charging system. This system would be applied on congested highways around the major cities in the morning peak period whereby no physical barriers are needed that could disrupt traffic.
The goal of applying this measure is to change travel behaviour for a part of the travellers and to create an important reduction in congestion. The time-accessibility of the main cities would therefore improve substantially. For the AIUTO experiment, cordons were created around the four major cities in the Randstad. For city-inbound traffic by car in the morning peak period (between 7:00 and 9:00 hours) a charge of Dfl. 5.- is applied.

D2 Parking management

Two types of parking management measures are implemented: reducing the number of parking spaces for commuters and implementing traffic management regulations enforced by companies.
Firstly, the number of parking spaces in so-called A and B locations is restricted for commuting purposes, especially at zones with good access to the rail network. The number of parking places available is limited to a fraction of the working places within those zones. The surplus of car arrivals for commuting purposes is redistributed amongst the other modes and neighbouring arrival zones.
Secondly, car-use could be reduced by the implementation of traffic management regulations by companies. Companies generate commuting traffic, a substantial proportion of peak period traffic. The resulting contribution to congestion can be reduced by the companies themselves by creating and enforcing a transport plan for their employees, where various measures are combined to reduce the amount of cars allowed to at the employment zone. These transport plans (for companies having over 50 employees) contain measures covering a wide range of possibilities related to the promotion of bicycling, car-pooling, public transport, tele-working, wider range of working hours, different travel cost benefits and parking.
The traffic management regulations as implemented in the model limit the number of cars for arriving for companies, which is implemented in a comparable way as given before under “reducing the number of parking spaces”, with the exception that an alternative parking location at neighbouring arrival zones not an available option. Therefore, the surplus of arriving cars at a arrival zone (having traffic management restrictions) is distributed over the other modes. The measure is implemented such that a reduction of 6.2% on the total car driver kilometrage for commuting traffic is achieved (as compared with the reference case).

D3 Public Transport measures

Public Transport measures are often implemented to improve the quality of public transport such that a good (or better) alternative to private transport in congested urban areas is provided as well as to reduce use and thus the environmental impact of cars. There can be several ways of implementing PT measures. In the current work we have focused on improving the *speed* of Public Transport both locally and area-wide. The speed of Public Transport is improved locally for a set of OD relations, reflecting various means of High-quality Public Transport, such as light rail. General speed increases for PT are implemented by increasing the speed relatively more for the shorter distances of travel than for the longer distances.

D4 Fuel pricing

By increasing the price of fuel, variable costs of car-use are increased which has as a goal to reduce the total car kilometrage and lost hours in traffic queues. This measure is normally applied to promote to less car use and also more efficiency. An increase in the variable car costs will also promote the use of Public Transport.
An experimental policy is implemented where the variable costs of car use are increased with 8%. In this figure, both increasing costs for fuel and the reduction in fuel consumption due to better

efficiency of cars are taken into account. The 8% growth in variable costs of car-use per km is based on a comparison of the variable car costs between reference situation and the implemented measure situation. In the reference situation fuel price index is 116 and efficiency index is 83, yielding a variable cost index of 96.3 for the reference case (all indices: 1990=100). For the implemented measure situation, fuel price and efficiency indices are 130, and 80 respectively, giving a variable cost index of 104.0 (again all indices: 1990=100). The implemented variable car cost measure is thus the relative increase in variable car costs between the reference situation (index 96.3) and the measure situation (index 104.0), which amounts to the increase of 8% stated before.

TDM Packages

Packages are sets of TDM measures (usually more than one measure but for one package (build) only a single measure defines the package). The incremental effect of the measures may be inferred from comparisons of indicators (MOEs such as kilometrage, travel time or consumer surplus) as between different packages. The issues of package **combination** and of effect **time-path** (long-run/short-run variation) are explored by the same means, as outlined below.

There are *five* packages which will allow estimation of combination possibilities, and *four* which will look at time path.

The package combination runs consist of the following:

A	an 'absolute base' run of measures
A.B	**A** measures with **B**uild options of new infrastructure
A.C	**A** measures with **C**ontrol options to assist highway flow
A.D	**A** measures with **D**eterrence measures to the car mode
A.B.C.D	the complete set of measures

For each indicator, the marginal effect of **B** can be taken as the ratio of the indicator value for **A** and the value for **A.B.** Similarly for **C** and **D,** and also for **B.C.D**. By comparing the product of the marginal effects for **B**, **C** and **D** with that for **B.C.D**, we can infer whether or not there are interactions. If the combined effect of the separate measures *exceeds* the effect of the sum of the measures, we can conclude that the measures reinforce each other. If the comparison shows the combined effects as *less than* the effect of the combined policies, we can assume the measures work to reduce each other's influence in some way. In either case, we would be warned to use the *model* directly to evaluate combined policy packages, rather than simply to add combined impacts from separate model runs evaluating separate policy sub-components.

The total number of TDM packages analysed using various combinations of TDM measures are therefore nine. Results of each of these packages are compared with the **A** scenario, which actually is a 'realistic' central prediction for the year 2005 under the 'European Renaissance' scenario.

Two TDM packages are implemented where, in addition to the packages as described above, the model option "Destination Constraint" is applied. Using this model option, short term effects of each of the packages can be analysed, as opposed to the Long Term effects which are modelled in the other packages.
In using this "Destination Constraint" model option, the choice of destination for travel for all purposes is restricted to those modelled under a reference base case (see later). This allows for modelling of short term effects of TDM packages in which travel mode and departure time are allowed to be influenced by the package, but the travel destination remains that which would have been chosen in the base case.

A.[C] in addition to the measures as previously described under **C**, the model option "Destination Constraint" is applied.

A. [B.C.D] the **B.C.D** measures are applied in addition to the **A** base, but using the model option "Destination Constraint" in order to model the short term effects of this package.

The five groups of packages which will contribute to the consideration of differences in time-scale to full policy impact are **A**, **A.C**, **[A.C], A.B.C.D** and **A.[B.C.D.]**, using the same type of notation as above. As with the 'combination' runs, we actually work with the ratios of **A.C** to **A,** giving us **C**, **[C]**, **B.C.D** and **[B.C.D]** as the input growth factors. It follows that we are interested in the ratios of **C** to **[C]** and **B.C.D** to **[B.D.C],** which set out the growth/decline in the policy impacts from the short-run to the long-run.

5.5.3 Data

A broad range of transport and socio-economic data is available for the Randstad. Many of this data is used in the national traffic forecasting system (NMS).
The NMS zone system, represents the Randstad with 144 zones, out of 345 national zones. At the subzonal level, the Randstad consists of approximately 500 subzones. The main road network is described by approximately 12000 links and an explicitly coded rail network is also available.
Traffic count data (peak periods, weekdays) for urban and interurban highways are available from the national and regional traffic data collection programmes. Many counts differentiate between cars and lorries. Apart from permanent count stations, a significant number of periodical and incidental counts are available.
Socio-economic information is available for each zone in the NMS system. This data includes the number of jobs by category, the number of cars, the number of employees by sex, the number of students, the number of inhabitants by age and sex and the number of households.

5.5.4 Modelling Framework

The LMS/NRM model system has been used within AIUTO. The general structure of the model is as given in Figure 43. The traffic forecasting system for Randstad is capable of modelling the following travel dimensions:

- **driving licence** acquisition
- **car**-ownership
- **tour** frequency for home based travel, **trip** frequency for non-home-based
- choice of **primary destination** and **mode** for home-based **tours** and non-home-based **trips**
- **time of day** choice for trips
- trip **route choice**

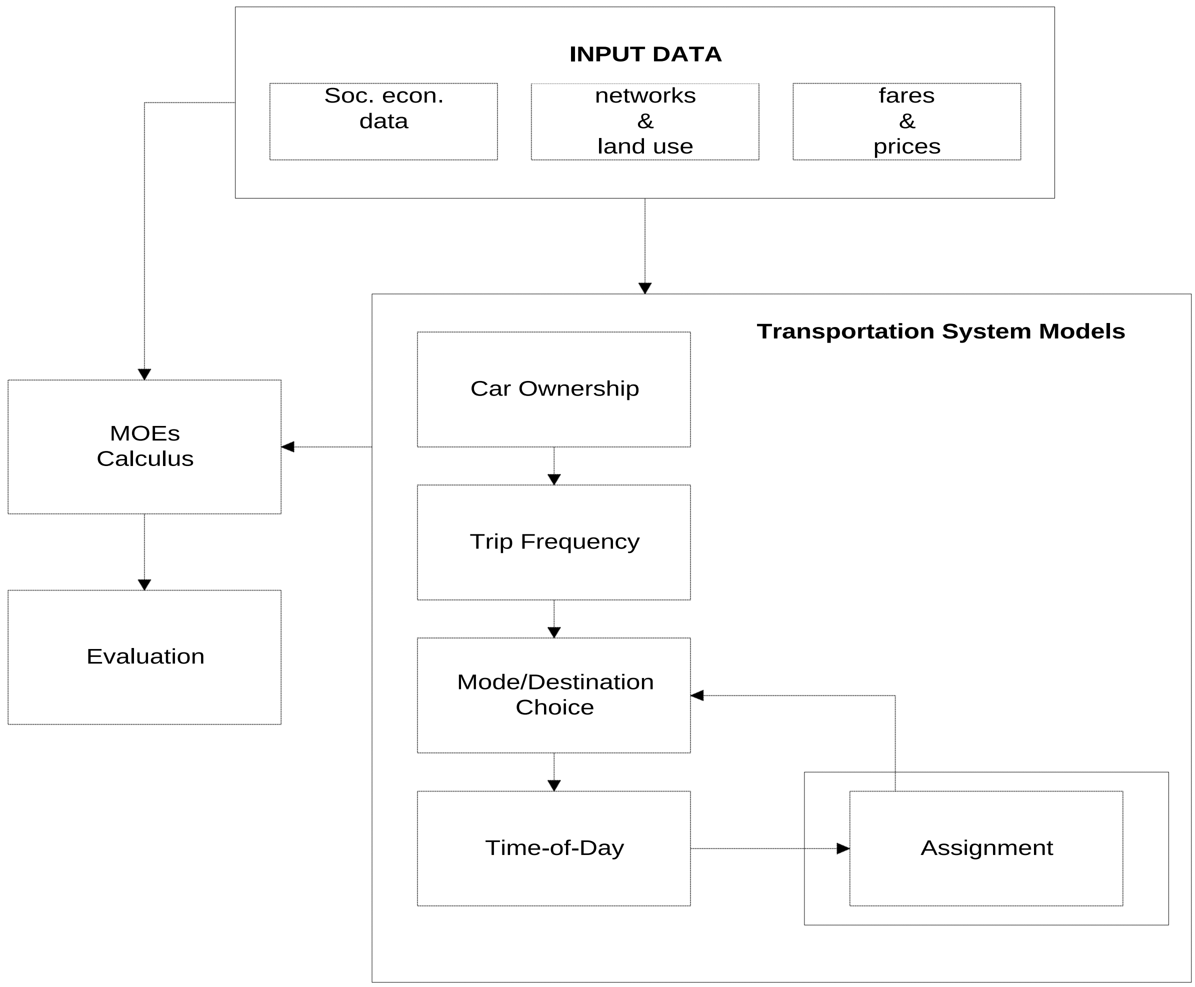


Fig. 43 – Randstad modelling framework.

The model system is also responsive to different societal developments in terms of work-hours and holidays, the development of telematic practices replacing some travel needs, fuel consumption implications of developments in automotive engineering, and can represent behaviour under different types of extreme parking policies. The influence of different policies concerning land-use and transport networks, and of different scenarios concerning socio-economic and demographic changes, is also represented.

The tour concept has been introduced into the system for reasons associated with behavioural realism; most travel patterns involve leaving the house for one particular activity - be it work, education, shopping or other. Secondary (and subsequent) destinations may be visited in the process, but their frequency (and mode and location) is frequently dictated by the demand for the 'primary destination' and how the choice of frequency, travel mode and destination is resolved for that activity.

For this reason, tours (sequences of trips linking destinations visited from leaving home to returning) are reduced to two trips between home and the primary destination for that (minor) proportion of tours involving detours. Time-of-day choice is represented separately for outward and inbound legs; i.e. at a trip level. Finally, growth in tour 'legs' by time of day is used to imply growth in trips recorded in a 'base matrix' of trip movements, leading to a forecast trip matrix for assignment.

The policies being tested in the Randstad project are designed to influence mode and destination choice, time of day choice and route choice; other aspects of the forecasts are held constant and will not be elaborated here.

The model system covers 6 travel purposes;

- home based work (commuting plus home-based non-business-work travel)
- home based business (briefcase travellers, not blue-collar or occasional workers)
- non home based business
- home based education
- home based shopping and personal business
- social, recreational and other

The travel modes being distinguished in the model system are:

- car driver;
- car passenger;
- public transport (with breakdown possible to rail, tram, bus, metro);
- slow mode (with breakdown possible to walking, cycling and moped).

Typically, the models that are fitted are static equilibrium models, which is to say they assume either that patterns of demand in the any year are 'in equilibrium' with travel conditions in that year. Crucially, they assume that between the base and any forecast, the full effects of any changes in policy, infrastructure or background variables, as determined by the model, will feed through. However, experience has shown that there will usually be a period of adjustment to any change of conditions. For example, considering the effect of a high petrol price policy in the year 2000, were the rise to take place one year before, different travel patterns might be expected in 2010 than if the same was made ten years previously. This aspect is also investigated in the model application within AIUTO project.

5.5.5 Results from Modelling

Table 44 sets out some runs from the 'combination' runs, for a selection of 'MOEs'. for each of a number of output forecasts, car-driver all-day kilometrage and so on, factors are provided to relate the policy package results to the **A** run. Thus if there were 1000 km in the **A** run and 1020 km in the **A.B** run, under the column **B** would appear 1.020. similarly for other indicators.

Thus we have eventually 'output factors' for **B**, **C**, **D**, and also for **B.C.D**. The question is whether or not the product of the first three factors is 'close-enough' to the fourth; if so, we could have approximated the fourth run from the first three.

In a simple one-stimulus/one-response model, this would be a problem to tackle in terms of the local linearity of the response curve, given the base level of the base stimulus and the size of the changes implied by **B**, **C** and **D**. However, whilst the LMS system is essentially a cascade of multiple stimulus/response calculations (some with discrete responses, some continuous), the end result is certainly not a simple function! We can say in general that for continuous response curves the smaller the changes in the stimuli the more linear will be the curve; but 'how small' is 'small enough' remains to be seen.

AM peak	B	C	D	B*C*D	B.C.D	B.C.D/ B*C*D
CO	1.07	1.06	1.06	1.07	1.06	0.99
Car commuter km	1.056	0.987	0.756	0.788	0.787	1.000
Car business km	0.980	0.981	1.239	1.191	1.270	1.067
Car other km	1.022	0.993	0.688	0.698	0.708	1.014
Flow/cap ratio <70%	1.014	1.014	1.025	1.054	1.042	0.990
Flow/cap ratio 70-90%	0.984	0.981	0.838	0.809	0.841	1.040
Flow/cap ratio >90%	1.116	0.955	0.782	0.833	0.932	1.119
Av. Speed non highway	0.989	1.028	1.105	1.123	1.076	0.959
Av. Speed highway	1.031	1.026	1.128	1.193	1.202	1.007

Table 44 - Some Combination Package Results (base = 1.000)

These statistics are fairly typical of other similar statistics to come from the experiment; we can identify some ‘sensitive’ outputs for which combination may mislead amongst a majority for which the impact is small. From the above, we might pick out car-business am kilometrage and the ‘bottleneck’ kilometres with flow/capacity ratios over 90%.

The 7% difference between the ‘combination of packages’ and the ‘combined package’ runs seems to be due to the forecast impact of the extra infrastructure. On its own, this attracts extra traffic at sensitive locations for the morning business traveller (despite overall average network speed going up), arising from the increase in commute and other travel, as well as making off-peak (commuter-free) journeys more attractive. When the ‘Control’ and ‘Deter’ policies are applied, the lower value-of-time travellers on non-business trips switch out of peak-hour car-use, raising speeds and reducing delays for the business driver.

The discrepancy in the effects for the overloaded links in the flow/cap>90% category probably arises because the ‘Control’ and ‘Deter’ policies each separately reduce the *same* bottlenecks; put together, their sum effect cannot equal the sum of their separate effects.

It is intended that further analysis is given to the larger body of results; these will be reported in due course.

Table 45 sets out another set of results from the ‘long-run/short-run’ tests, illustrating the sort of results we have obtained. The table displays percentage changes from a slightly different base, a ‘time origin’ **O**, progressing from **[C]** to **C** and from **[B.C.D]** to **B.C.D**. **O** is in fact **A** without ramp metering.

	O ® [C]	**O ® [C] ® C**	**O ® C**	**O ® [B.C.D]**	**O ® [B.C.D] ® B.C.D**	**O® B.C.D**
All day						
Car driver km	+0.5	+0.9	+1.4	-2.8	+0.6	-2.2
Car passenger km	+0.8	+0.6	+1.4	+8.9	+3.5	+12.4
Public transport km	-2.4	+2.8	+0.4	-0.3	+6.1	+5.8
Slow mode km	-0.2	-0.2	-0.4	+1.2	+0.2	+1.4
AM car trips						
Commute	+0.4	+0.7	+1.1	-3.8	-0.7	-4.5
Business	-2.1	+2.0	-0.1	+13.4	+8.4	+21.8
Other	-0.4	-1.2	-1.6	-16.3	-1.1	-17.4

Table 45 - Long-run/Short-run tests: % changes

Starting with the all-day kilometrage % changes, and looking first at the **C** package (control, mostly of car traffic streams); the way in which 'short-run' has been defined constrains the kilometrage to be the same between **O** and **[C]**, so that the only permitted changes are mode split (and time-of-day). The measures clearly improve road traffic flow, and increase car-carried mode share at the expense of both public transport and slow modes . However, the public transport-promoting aspects of the policy (including bus-lanes but also restricted car-access to sensitive sites) produce a counter-balancing growth of 'new' kilometrage when the traveller is allowed to reconsider destination as well as mode.

For the more comprehensive **B.C.D.** package, with regulations introduced to promote the car-passenger mode through DM measures and HOV lanes, car-passenger takes kilometers (=trips in this case) from both car-driver and public transport in the short-run **[B.C.D]** package. This trend is accentuated in the longer run, although public transport benefits from the increased spatial penetration that comes from the speed increases in the Deter policy package and gains new ground.

In any case, the important message is that the path to the final policy effect is **not** smooth and immediate. In some cases, as had been predicted from the model elasticities, a final growth in demand can be preceded by an initial drop, or vice-versa.

It may be concluded that:
1) The Randstad methodology has proved applicable to the task of providing a scientific tool for planning TDM measures, in respect of the scenarios it can consider and output it can produce. It is particularly appropriate for regions.
2) Quite apart from the model methodology chosen, there are indications that a fruitful area of research might be the study of the 'multiple scenario' problem. The idea that policy measures might somehow be grouped into those effectively 'independent' (for which results could be approximated for complex packages from partial results for each measure, without having to return to the model each time) is attractive. However, it seems that in some cases this could be a dangerous assumption; as it is unknown how these should be identified.
3) Even given the somewhat crude nature of the identification of 'destination-constraint' with short-run behaviour, there seems no denying that travel behaviour develops to stimuli over time. The results developed for long- and short-run System Elasticities and for the time-path development of the Measures of Effectiveness by which policies may be judged, suggest that this may also prove a vital research area if modellers are to produce credible predictions, not just for a design year in a far-distant year, but for the time-path from forecast, to policy implementation, through response development.

5.6 York (UK)

5.6.1 Test Site Description

The City of York is situated in the North East of England and has an urban population of around 135,000. York District has approximately another 40,000 residents. It is a historic City which attracts large numbers of tourists as well as being a local centre for many rural settlements.
The City enjoys good transport links with the rest of the country being situated on the main rail line between London and Edinburgh. It is also close to the main road between the two capitals. The national cycle route network passes through York and although much of it is still to be constructed the section through York is complete.

An Outer Ring Road surrounds the City removing through traffic from the City Centre. One half of this is dual carriageway and the other half single carriageway. York has been operating full time Park and Ride services in the City since 1990. There are now three full time services and one part time.
Traffic signals in the City Centre are controlled by a SCOOT Urban Traffic Control (UTC) system.

The transport policy for the City of York is to limit the growth in car traffic so that the number of trips by private car into the City Centre during the peak hour in 2006 are no higher than 1992 levels. Excess demand for transport will be encouraged to use other, more environmentally friendly, modes of transport such as walking, cycling and public transport.

Park and Ride is already making a contribution to the overall transport policy. In 1995 almost 750,000 passengers were carried, keeping over 400,000 cars out of the City Centre. A total of five Park and Ride sites are planned for the City.

The 1985 Transport Act (UK) limits the influence which Local Authorities can have over public transport. The City Council is, however, improving the image and operating environment for public transport through bus priority measures, electronic bus information systems, improving and expanding bus shelter stocks, providing concessionary travel for elderly and disabled travellers and subsidising unprofitable evening and Sunday services.

The City Council controls about 5000 parking spaces in the City Centre. The tariff structure is designed to encourage short stay shopping trips rather than long stay commuters.

An extensive programme of traffic calming in the City has been undertaken with 20% of York now 'calmed'. The reduction of speed in these areas has resulted in greater priority to pedestrians and cyclists and significant reductions in accidents.
More information about the city's transport plans can be found in the document Transport Policies and Programme 1996-1997 available from York City Council.

5.6.2 Scenarios

The considered intervention concerns a bus-lane with two sections along a penetration axis to the city. The scenarios differ for the lane use: in the first case buses give the right-of-way at the end of the lane, in the second and third ones they do not, in the fourth and the fifth ones the car-poolers can go through; the last scenario adds a park pricing scheme. Packages I to V are intended to build upon each other.

TDM package	TDM measures	Applicability
Package I- Bus Lanes	Park and Ride, Access control	Westbound Corridor into City Centre
Package II Bus Priority Signals	Package I plus Bus Priority Signals on the Bus Lanes	(as for package I)
Package III After network	Package II plus lane closures and signal timing changes and minor infrastructure	(as for package I) plus outbound Park and Ride passengers
Package IV High Occupancy Vehicles	Package II with the bus lanes used as high occupancy vehicle lanes for >2 occupancy vehicles	(as for package I)
Package V High Occupancy Vehicles	As package IV but the HOV lanes are only usable by >3 occupancy vehicles	(as for package I)
Package VI Park Pricing	Package II plus Park Pricing in the city centre	Commuters travelling into the city. Park and Ride Users,.

Tab. 46 - A summary of the packages to be modelled on the York test site

Base Case

Base case network (BEFORE): This is the before network which is used for comparison with Packages I through V. It is a calibrated, validated, car only network with a fixed demand for the morning peak hour of a typical week day and was supplied by YCC. The network has over 30,000 vehicles in the peak hour. The network is for private vehicles and two of York’s Park and Ride routes. The network contains no bus lanes.

Package I

Bus Lanes (BUSLANES). By adding bus lanes to the park and ride route, YCC hopes to decrease travel times for inbound buses, particularly in the busy morning peak hour. Two stretches of road will be converted from mixed use (private and public transport) to being solely bus-lanes. Due to the layout of the route it is not possible to have a bus lane running the length of the route. Buses are assumed to give way to cars at the end of the bus route.

Package II

Bus Priority Signals (PRIORITY). The bus lanes will not be totally effective if, at the end of the lane, the buses are held up by having to force their way back into the oncoming traffic. Therefore this package will consider the addition of priority signals at the end of the bus lane stretches which give priority to the buses and delay the cars. This package is based upon package I with the addition of priority signals for buses. The priority signals ensure that vehicles using the bus lanes will always get a green phase when they arrive at the signals with one exception. For safety reasons it was considered unwise to interrupt one green phase on the western-most section of bus lane. Buses arriving in this phase will experience a slight delay but at all other times they will be given absolute priority.

Package III

Minor signal timing, access and infrastructure changes (AFTER). This package is intended to model the full extent of the changes to the network envisaged by YCC. While the changes to package II are, individually, of a somewhat minor nature, the package is of interest since it duplicates the scheme which will be put in place on street as precisely as possible within the models used. This package is based upon package II with the closure of a minor lane approaching the park and ride site to prevent cross traffic, a “cut” made to the network to allow buses returning to the Park and Ride site from the city centre direct access to the site (currently they must travel out further and loop round a congested roundabout before returning to the site). Finally, some minor timing changes are made to the signals at the Melrosegate Junction to the west of the park and ride site in the hope of decreasing delays for the inbound traffic.

Package IV

High Occupancy Vehicle Lanes (HOV2). This package attempts to assess the effects of allowing bus lanes also to be used by high occupancy vehicles. The package is based upon package III (base network with bus lanes and priority signals for vehicles in the bus lane) and considers the effects of allowing vehicles with two or more passengers to use the bus lanes.

Package V

Higher Occupancy Vehicle Lanes (HOV3) As for the previous scenario but only vehicles with three or more passengers are allowed to use the high occupancy vehicle lane.

Package VI

Park Pricing changes. This package attempts to model the effects of changes to Parking Pricing changes on the York network. As has been mentioned, one of the main methods of discouraging car usage in York City Centre is parking charges. This package attempts to assess the effectiveness of these park pricing changes.
The charge levels modelled were 2.9, 5.8, 8.7 and 14.5 ECU for parking. It was assumed that all drivers except those headed out of the city or those who parked at the park and ride site would have to pay these charges.

5.6.3 Data

The majority of the data used in this study comes from a SATURN model of the city, provided for the AIUTO project by YCC. The SATURN model was based upon one constructed by YCC in 1992 and extensively updated by them in 1996. In addition to this, the city council was able to provide information about Park and Ride routes, vehicle occupancy, Park and Ride fare structure and parking charges within the city. Value of Time data has been taken from the EU project TransPrice. Unfortunately, no representation of the city bus network was available except for the park and ride routes, therefore, full modelling of mode choice effects was not really practical in any realistic predictive way using the network based approach available in the York and Newcastle models.

The SATURN model contains the following data:
- 182 x 182 morning peak-hour trip matrix
- Free flow velocities, saturation flows and turning movements for 1293 links
- Turns and connections for 558 nodes
- Signal timings for the 63 signalised junctions in the simulation (where these junctions are SCOOT junctions the timings used are average times used by the SCOOT system)

In addition to this the council provided data on:
- Park and Ride occupancy
- Private Car Occupancy
- Park and Ride fares

Values of Time

The base value of time for the York study was taken from the EU funded project TransPrice, Deliverable D.3. The base value of time 5.36 ECU/hour which is an average for all car journeys in York was used for assessment in packages I to V. The SATURN network, however, was calibrated with a perceived value of time and a value of distance. It was important to keep the ratio of value of time and value of distance the same for the car network or the network would no longer be properly calibrated. For all the studies used, the car traveller perceived value of time in ECU per minute was always twice the perceived value of distance in ECU per kilometre. For packages I to V, the study only involved the car network therefore the values of time needed were the assessment value of time (5.36 ECU per hour) and the perceived values of time and distance for which only the ratio was important.

The values were multiplied by weights taken from THT Guidelines for Developing Urban Strategies (1996) in order to obtain values of time for different modes for package VI. These values were then used to obtain the generalised costs. The assessment value of time was split into values of time and distance in such a way that the total cost experienced on the base network would remain unchanged but the perceived values of time and distance remained in the same ratio.
The following values were used both for perceived values and assessment values:

- Value of Time (car): 4.07 ECU per hour
- Value of Distance (car): 3.39 ECU per 100 km
- Value of Time (walking): 10.72 ECU per hour
- Value of Time (bus travel): 9.39 ECU per hour
- Interchange penalty (for switching mode): 0.45 ECU
- Park and Ride fare: 0.87 ECU (the tickets cost 1.74 ECU each for a return)

In addition the vehicles were charged for parking (since the parking charge is paid only once for the inbound and outbound journey, the charge used for perceived value and for assessment was half the actual parking charge levied e.g. for a parking charge of 2.89 ECU the users would only be charged 1.45 ECU as part of the into town journey).

5.6.4 Modelling Framework

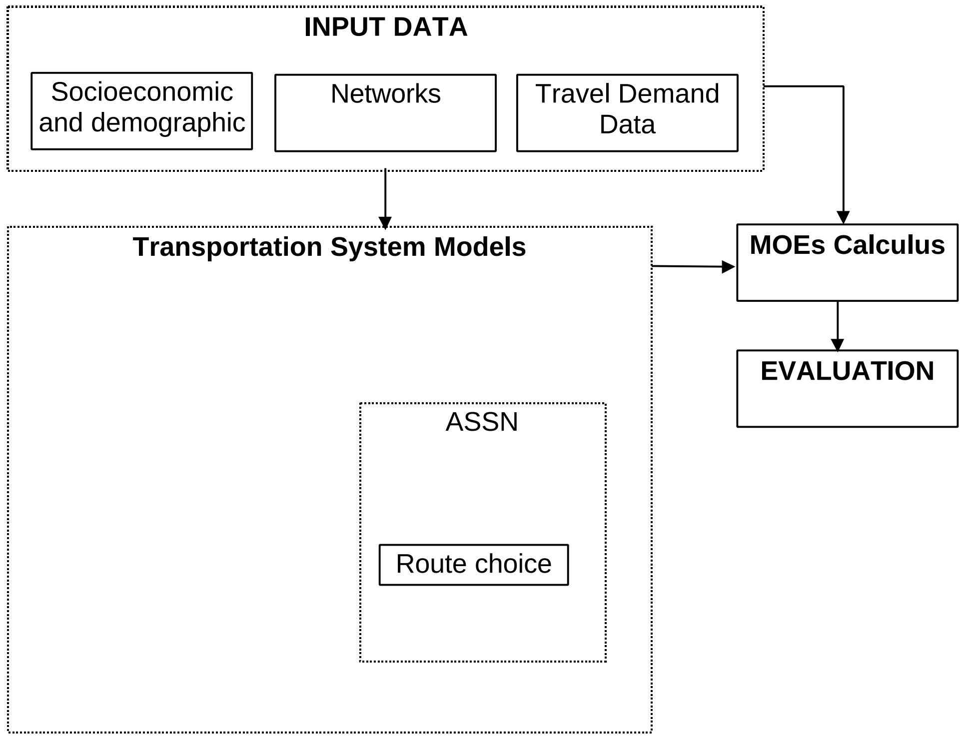


Fig. 47 – York modelling framework.

It can be seen from this revised diagram that the modelling in York concentrated on route choice issues and the supply side modelling which underlies this.

Four modelling packages are used by the three UK partners. The ITS used SATURN for estimates of most performance indicators and DRACULA for detailed pollution estimation. TORG used PFE for their modelling and YNCG used their program STEER. The choice dimensions modelled are, for packages I to V, route choice alone and for package VI route choice and mode choice. In the latter case the route choice and mode choice take place simultaneously with the mode choice seen as route choice on an extended network.

The following table presents a summary of the models used by the modelling packages within the AIUTO framework (note: this represents the packages as they were used within AIUTO rather than their full capabilities. For example, STEER can be run as either stochastic or deterministic user-equilibrium and SATURN has models for mode choice and elastic demand assessment available).

	STEER	**PFE**	**SATURN**	**DRACULA**
Supply model (simulation)	Microscopic Dynamic	Macroscopic Static	Macroscopic Cyclic Flow Profiles	Microscopic Dynamic
Demand Model (see below)	Fixed Matrix Integer values	Fixed Matrix Integer values	Fixed Matrix Real values	None Used
Assignment Model	Dynamic DUE Incremental	Static SUE Logit	Static DUE Frank-Wolfe	Taken from SATURN
Mode Choice Model	None Used	Within Assignment Model	None Used	None Used

Tab. 48 - A summary of the modelling packages used on the York Test Site

When comparing between different models a number of complex translation issues arise. While there is no space to go into them in detail, an account of some of the translation issues which arose during the AIUTO project can be found in (Clegg, Clune, Cassir).

SATURN

At the heart of the SATURN algorithm is an iteration between assignment and junction simulation. The assignment model estimates turning movements through junctions. These turning movements are fed into the simulation model which estimates flow-delay curves at junctions. These flow-delay curves are combined with the pre-defined flow-delay curves on links, and together they are used in a new assignment. In turn the new assignment provides new turning movements at junctions. This iterative process continues until sufficient convergence is achieved.

DRACULA

DRACULA is a microscopic dynamic traffic assignment and simulation model of traffic networks; the demand and supply sides of the model interact with each other on a day-to-day bases. For the York study only the traffic simulation part of it is used with route assignment provided by SATURN. The routes chosen by SATURN are fed to the DRACULA simulation model which, in turn, feeds its output to the DRACULA pollution estimation model.

The traffic simulation of DRACULA is individual vehicle based microscopic simulation of junctions, links and lanes. Vehicles follow pre-determined fixed routes from their origins to destinations, en-route they encounter queues and traffic controls. The positions and speeds of each vehicle are updated every one second according to car-following, gap-acceptance and lane-changing rules and traffic regulations.

The emission sub-model of DRACULA obtains detailed traffic condition directly from the traffic simulation. Coupled with disaggregated emission rates by driving mode (acceleration, deceleration, idling or cruising), the emission model predicts instantaneous exhaust emission and fuel consumption.

The emission factors used are taken from the QUARTET Deliverable D.2 (1992). Emission rates for three pollutants are available: CO, NOx and unburnt hydrocarbon emission. The model assumes that emission factors are constant for vehicles waiting in a queue (idling), accelerating or decelerating. For vehicles cruising at a constant speed, the emission factors are assumed to be as a function of speed.

PFE

TORG used their model Path Flow Estimator (PFE). The PFE is a stochastic user equilibrium model formulated as a non-linear mathematical program in the path flows variables. The solution of the program gives path flows (and consequently link flows) according to the Logit route choice model. Congestion effects are taken into account through flow dependant link cost functions, and the equilibrium between travel times and flows is attained using the method of successive average (MSA) in the algorithm that solves the mathematical program. Paths are built at each iteration of the program by a least cost procedure, the Dijkstra algorithm, therefore avoiding the need for paths enumeration.
Even though the link costs functions utilised allow for link capacities to be exceeded (resulting in queue formation), the PFE is essentially a steady-state model which was run in this study for the morning peak hour trip matrix, without ‘warming up’ period.
The PFE can also be used in multi-modal networks where the route and mode choice are treated simultaneously with appropriate generalised costs for all modes. Path flows representing trips by any modes are then computed in the same manner (the Logit model) as in the single mode case.

STEER

The STEER modelling package uses the following modelling elements in the AIUTO study:

- Dynamic deterministic user equilibrium assignment
- Microscopic junction simulation
- Fixed speed flows on links
- A fixed trip matrix which may be split between modes
- Fixed park and ride bus routes
- Assignment between modes as part of the route-choice process

Within AIUTO, STEER is used as an equilibrating model tending toward a Deterministic User Equilibrium. The program iterates between assignment and simulation with the assignment phase, naturally, providing routes for the simulation phase and the simulation phase providing revised travel time estimates for the assignment phase. The STEER model attempts to equilibrate the network by assuming that users each attempt to minimise their costs. In the modelling presented here, departure time is fixed and the choices available to the user are mode choice and route choice. The assignment model used for AIUTO was relatively simple. On each iteration, a “shortest path” through the network is calculated for each traveller based upon the travel times of previous iterations. The travellers consider switching to a new route based upon the gain it offers over their current route. The greater the cost-saving offered by the new route the greater the chance of a driver switching to it for the next simulation iteration.

5.6.5 Results from Modelling

York is a little bit different with respect to the other case studies because the simulated measures are strictly located and they have their impacts essentially on travel time and route choice, not on mode choice.
The main conclusion of this modelling exercise was that the partial bus-lane scheme (as studied in AIUTO) is not an effective method for speeding up public transport. In other words, the schemes as defined were not sufficiently strong enough, *by themselves*, to have a significant improvement on bus journey time. The scheme studied produced no significant improvement to bus travel times and only in some cases produced a benefit. The failing raison can be found in the fact that the lane is too short: the merging junction at the end of the lane presents delays similar to the advantages acquired along the way.
Given that the schemes were predicted to have negative effects on car traffic, this could be seen as a disappointing result. However, the positive conclusion to be drawn from the exercise is that

bus lane and HOV lane schemes should be much larger in scale in order to provide the necessary reduction in journey time to encourage people to switch mode from single-occupancy cars.
This result confirms the basic premise that *strategic policies* rather than aggregates of local policies are required in order to get overall city-wide results. However, bus lane schemes and HOV schemes can of course form elements in an integrated strategic policy.

There were two main modelling foci in the study:
1. The difference between deterministic user equilibrium (DUE) and stochastic user equilibrium (SUE)
2. The difference between traffic microsimulation models and less detailed models of traffic

	Model	Base	Bus-Lanes	Priority	HOV2	HOV3
km (car)	*SATURN*	49851	+0.1%	-0.1%	-0.1%	-0.1%
	PFE	31240	+0.0%	-0.1%	+0.3%	+0.3%
	STEER	22491	+3.9%	+2.5%	+2.6%	+2.9%
Average Speed (km/h)	*SATURN*	37.6	+0.3%	-0.3%	+0.3%	-0.3%
	PFE	39.7	-2.5%	-3.0%	-3.0%	-3.0%
	STEER	27.2	-3.7%	-4.0%	-5.1%	-3.3%
Congestion indicator	*SATURN*	0.608	-0.8%	-2.0%	-2.6%	-1.3%
	PFE	0.575	-4.7%	-3.1%	-4.3%	-4.3%
	STEER	0.959	+1.1%	+1.5%	+4.3%	+0.8%

Table 49 - Cordoned network results

	Model	Base	Bus-Lanes	Priority	HOV2	HOV3
Bus inbound Travel time (min)	*SATURN*	10.83	-0.6%	-2.9%	-2.9%	-4.1%
	PFE	8.22	-3.8%	-4.1%	-3.8%	-4.7%
	STEER	9.10	-1.1%	-4.4%	+1.1%	+2.1%
Car inbound travel time (min)	*SATURN*	5.72	+8.9%	+12.4%	+9.6%	+11.5%
	PFE	4.7	+6.4%	+23.4%	+6.4%	+8.5%
	STEER	3.90	+12.8%	+38.5%	+38.5%	+30.5%
Rat Run Flow level (vehicles/h)	*SATURN*	748	+8.4%	+15.4%	+9.0%	+11.5%
	PFE	1720	+6.1%	+11.0%	+8.7%	+10.4%
	STEER	1611	+0.7%	+0.6%	-1.3%	+4.2%

Table 50 - Local (Hull Road and Rat Run) indicators

As far as the York case study is concerned, there was little difference (of importance) in results from SATURN (DUE) and PFE (SUE).
The bigger model differences concerned issue (2). The conclusions from the case study with respect to (2) are that traffic microsimulation models should be used for the following purposes:
- assessment of the effects of reactive traffic signal schemes;
- accurate estimates of pollution;
- accurate estimates of (good) safety indicators.

With regard to pollution estimates in particular, if accurate absolute (as opposed to relative) estimates of pollution are required by a strategic model, it is highly desirable if the pollution sub-model of the strategic model is "calibrated" by a microsimulation model.
If, though, a traffic microsimulation model is to be used it must be properly calibrated with respect to delays of traffic on minor arms at give-way junctions.
On the other hand, if assessment does not involve any of the above issues, it is sufficient to use either a macrosimulation traffic model (PFE) or a mesosimulation traffic model (SATURN).

MoE	*Model*	Base	Bus lanes	Priority
CO (kg)	*SATURN*	404	+0.5%	+2.0%
	DRACULA	720	+4.9%	+3.9%
Nox (kg)	*SATURN*	88.0	+0.7%	+1.7%
	DRACULA	16.3	+3.7%	+2.5%
HC (kg)	*SATURN*	72.3	+0.6%	+2.2%
	DRACULA	55.0	+5.6%	+4.7%
Fuel Consumption (litres)	*SATURN*	4779	-0.1%	+0.6%
	DRACULA	4238	+3.0%	+2.7%
Travel time (pcu-hours/hour)	*SATURN*	1290	+0.0%	+0.4%
	DRACULA	1175	+3.2%	+5.0%

Table 51 - Environmental indicators, cordoned network

Finally, it must be pointed out that studies of an extended version of the bus-lane show that it would be effective if it were longer. The final system, studied in the MUSIC project, used the same length of bus lane but with the signals as a gating system to produce some benefit to buses. Small measures such as this scheme may be successful as a part of larger packages of measures.

5.7 Thessaloniki (GR)

5.7.1 Test Site Description

Thessaloniki Greater Area (TGA) is an urban agglomeration in the Northern part of Greece with a total population of approximately 800,000. It consists of 15 municipalities the most important of which is the City of Thessaloniki with approximately 500,000 inhabitants. TGA is located at the Gulf of Thermaikos and it has expanded along the coast line. The central part of the city is built on the ruins of the old city and is a rather narrow strip between the coast line (south) and the nearby mountains (north). Today the TGA has a “butterfly” (narrow body - extensive edges) shape.

Thessaloniki was founded by Cassandros in 316 BC, to be the new capital of Macedonia. The idea was to built a coastal city, with a safe port, so that Macedonia can secure sea communication with the known world of that period. The selection of the site proved to be very successful, as Thessaloniki became political and cultural capital of Macedonia along the centuries.

Thessaloniki is very densely populated with high rise buildings (especially in the centre), and inadequate road infrastructure.

Role and Position

Thessaloniki is the second biggest city in Greece after the capital, Athens. Its geographic site, makes it very important in terms of commercial, cultural and political interest. The port of Thessaloniki is the second largest in Greece after Piraeus. The fact that 90% of sea movements of Macedonia each year are carried out from its port, is a sound example of the importance of Thessaloniki in the greater area of the Balkans. It is also essential to highlight the importance of the city not only for the Balkans, but for Europe as well, as it is one of the main gates for goods transport in south-eastern Europe.

Large-scale works, as the construction of the gas pipe line and the new Agnate Road, will give a new, more potent role to the city in the greater area. More specifically, the construction of Agnate (Egnatia) highway (on the traces of the old Agnate during Roman period), will improve East West transport connection, making Thessaloniki the cross-roads of the Balkans.

Traffic Characteristics of Thessaloniki

As it is mentioned previously, Thessaloniki has a “butterfly” shape with the old city, which is also the city centre, being in the middle narrow part. The road network in this area has a grid pattern which extends to the east and the west. However as the city widens at its two edges the networks becomes radial. Thus, all the main roads which are parallel to the sea coast and have an east - west direction need to come through the centre.

More specifically the centre, the most important part of the city in terms of traffic, is crossed by 6 main parallel roads which run along the coast. Only one of them is two-way street (Agnate St.), while the others are one-way streets. Because of the topography of the area, there are not main vertical roads with heavy traffic flows.

In order to relax traffic in the city centre and remove through and heavy traffic from the residential areas, a ring road was constructed at the north east area of the city. The ring road was fully opened 3 years ago, though some road section are in operation since more than 12 years. According to available data, the ring road operates already at capacity during peak periods. The reasons for this are twofold; first there is a lack of at-grade intersections at certain locations; second the roads created new demand, rising in this way the total daily trips in the area. As a result of that, and partially due to the poor geometry of many radial connectors (obliged to cross mountainous areas), traffic in the city is still heavy.

Focusing on the centre, it is important to mention that there are in practice four main gates that allow traffic to enter or exit that area. Two of them are at the East end (Sintrivani, YMCA), and two at the West end (Vardari, Dikastiria). The latter are also the gates for the incoming traffic form the external areas. However heavy traffic does not use these gates, since it is diverted much earlier either at the west end of the rind road or at the beginning of an incomplete inner ring road. The Eastern gates carry heavy volumes of mixed traffic which enters the centre during morning peak and leaves during afternoon during peak periods.

Parking (On-Street/Off-Street)

Another major factor contributing to the existing traffic problems, is the lack of adequate parking space, especially in the city centre. The problem seems to migrate to most areas of the city, due to the rapid increase of the car ownership and the lack of parking space off street (underground garages, etc.). As a consequence of this, illegal parking, for both residents and visitors has been a daily necessity, very often with the tolerance of the traffic police. Parking in double parallel rows, or vertical parking in prohibited areas are common phenomena, leading to road width reduction and hence reduction in road and network capacity. The same phenomena are also met in other areas, but at a milder manner.
The city has a lack of organised parking areas (roofed or open). Some years ago a multi-storey car park was built at the West entrance of the city (Dikastiria), serving a significant number of car users (1100). Another open car park area exists at the eastern entrance of the city (YMCA) serving approximately 1200 cars. This car park belongs to the Municipality of Thessaloniki and it is free of charge. Some other smaller parking areas are scattered in the city centre area but they are not enough to cover demand. The legal parking spaces in the city centre are less than 10,000, the demand being more than 25,000. The construction of an underground car park at the northern part of the city centre which started 2 years ago stopped because of the discovery of ancient ruins.
Certain parking demand management policies (parking permits), have been proposed to be implemented through recent traffic management studies. The same studies suggest the implementation of new bus lanes or the extend of the existed ones, in combination with pedestrianisation and traffic calming and restraint measures in certain parts of the city. Physical measures are also suggested to direct the traffic and improve the existed road capacity. The first of the two new bus lanes proposed, is to be implemented soon.
Here, it is necessary to mention the difficulty in the completion of the proposed measures, as for small-scale schemes there is not an organisation to co-ordinate their implementation in the whole city. Instead, different parts of the city belong to different authorities and the planner should communicate with each of them. Therefore, it is unknown whether the proposed measures will be implemented soon.

Public Transport

Public transport has a significant role in the traffic of Thessaloniki. The Thessaloniki Transport Operator (OASTH) is a private co-operative organisation which has a 20 year concession agreement with the government to offer public transport services in the area. OASTH is subsidised by the Central government. It has a fleet of 488 buses (173 of them are articulated) and runs 50 different lines. The level of service offered by OASTH deteriorates gradually, especially during peak hours, as the number of buses cannot be increased due to the existing concession agreement.
Most public transport lines follow the main road axes which run from east to west or vice versa, thus creating a high concentration in the city centre. Though many terminals have been removed from the central area, there is still a significant problem with accommodating the large number of buses starting or ending their routes in that area. Along Agnate St., the most heavily trafficked road, 35 different bus lines run, causing severe problems to traffic and lowering passenger service.
In order to tackle this problem and to prevent the obstruction of traffic from illegally parked vehicles, two bus lanes were implemented some years ago. The first and most successful was established in a two-lane, one-way road in the city centre. The second one along one of the main East city entrances, outside the central area. The bus lanes were combined with some minor traffic changes and, in some cases, the shopkeepers of the implemented area were against them. Generally, there were no changes in traffic signalling or other major traffic management measures.

The positive results of the existing bus lanes led the municipality to consider the introduction of a third bus lane, along one of the main four-lane, one-way streets in the centre of Thessaloniki (Tsimiski St.). It is believed that this bus lane is very likely to be implemented within the next 12 months. The next step will be the establishment of a fourth bus lane on both sides of Agnate Street (mentioned above), but the time period has not been defined yet. The latter depends on the metro line which is expected to be constructed and will run below Agnate Street (its total length will be 9.3 km).
Both bus lanes with the relevant changes in traffic signalling will be included into the simulation part of the project, in order to test their efficiency.

Traffic Control Systems (Traffic Signals)

Thessaloniki is equipped with many traffic signal units which control traffic along most of the city roads. The number of signals exceeds 300 units in the TGA. However, all those units do not belong to the same authority; half of them are under the Regional Directorate of the General Secretariat of Public Works, whereas other to the local Municipal Authorities.
A new UTC system has been recently installed, but so far no traffic signal integration has been achieved.
Traffic signal operate with fixed-time programs which are based on the time period within a day and sometimes on weather conditions. At most of the road corridors signals operate in progression with speeds varying between 40 and 70 km/h. Apparently at locations where signals change jurisdiction a lot of problems appear.

5.7.2 Scenarios

The scenarios tested within AIUTO combine packages of TDM measures along with *major new infrastructure* (the so called Long Term measures). The reason for this is that the existing infrastructure is mainly used for long trips and it is not possible to implement great scale TDM measures that will have a severe car restraint effect without affecting socially and economically large portions of inhabitants.
Another reason is that new major transport infrastructure is being studied and expected in the near future, and most of the TDM measures being planned are expected to work in parallel or after the new infrastructure is in place.
Two major new infrastructure projects were included in the tests, a new metro line, which will create modal shifts from private to public transport and a new arterial tunnel bypassing the city centre which will mainly have a route change effect. The TDM measures examined in combination with the new infrastructure in an incremental manner include tunnel pricing (tolling), parking pricing in the city centre, pedestrianisation, traffic calming and bus priority measures.
Of course in the AIUTO runs the TDM measures are examined at an incremental manner, and once the impacts of the new infrastructure have been estimated.
All TDM measures tested in Thessaloniki were tested for a target year. The target years has been 2005. The Demand Matrix for the target year was based on the existing trends as well as on the expected car ownership index.
The following sections pertain to the TDM measures tested in Thessaloniki for each specific TDM measure category.

Long Term Measures (New Infrastructure)

The following long term measures were incorporated in the Thessaloniki tests:

Full Metro Line

A Metro line is to be built in Thessaloniki. The line is 9.3 km long with 14 stations. Currently negotiations between the responsible Ministry and the candidates concessionaires are being taken place. The Metro will change the modal split in favour of Public Transport. It will also change trip patterns in the area affected. Recent demand forecasting studies indicate the size and geographical distribution of the trips to be diverted from private transport to the new metro line. These expected impacts are taken into account in testing the implementation of the metro line.

New Tunnel Arterial

A new tunnel arterial for bypassing the city centre is being studied. The new arterial will connect the areas east and west of the city centre in such a way so that cars will not be obliged either to follow central corridors or the eastern ring road which lacks good connectors to the city centre. The tunnel will be approximately 1.3 km long and it will have 3 lanes per direction. Maximum speed is set at 80 km/h. The new road will serve only light vehicles. The existence of tolls has not been decided yet, but it will be examined for both reducing the expected high demand and for covering the maintenance cost of the project. The new arterial is expected to have a very strong impact on the traffic conditions in the city of Thessaloniki as well as in the everyday traffic patterns. The whole project will be the start of many other interventions falling into other TDM measures categories.

Other Infrastructure Measures

Certain changes in the existing network which have been already started or scheduled have been included in the scenarios of the target year. These changes mainly have local impacts or impacts limited to specific areas and they are expected to change significantly the behaviour of the trip makers.

Pricing Measures

One pricing measure is only examined for Thessaloniki. The measure pertains to the tolling of the new tunnel arterial in order to control demand. The toll level will be equal to 200 Greek Drachmas, or approximately 2/3 of an ECU. This amount is equivalent to 15 minutes of an hour, according to the average value of time of car trips.

Regulatory Measures

Regulatory measures aim at providing motives to trip makers to quit or reduce usage of private cars or to strengthen those who already use environment friendly transport modes including walking. They also aim at making car usage more difficult. Regulatory measures are distinguished in this respect in **pull** and **push** measures.
The following measures are tested in Thessaloniki for the AIUTO project.

Traffic Calming

Traffic calming measures are foreseen for specific central areas of the city of Thessaloniki. The most important measures have to do with narrowing a main arterial road by one lane and reducing the speed limit in this and other main streets. Traffic calming aims at reducing transport demand along certain corridors as well as in the city centre.

Pedestrianisation

In a similar fashion certain roads are to be pedestrianised in the near future. Pedestrianisation will cause traffic reallocation, especially in the city centre. It will also reduce parking supply.

Parking Management (New Parking Policy in the City Centre)

Two recent studies about parking in the city centre indicate that a new parking policy is required for this area. This new policy favours parking fee raise, causing in this way reduction to the average parking duration. Additional parking spaces should also be secured to replace the illegal spaces which will be given back to traffic. Today, illegal parking is a severe congestion factor. Similarly, an equally important factor contributing to congestion is looking for a spot to park. Special measures, such as parking permits, will be taken for permanent residents of the area. The proposed policy is expected to reduce car park space search time, but at the same time to increase capacity of most city centre streets.

Public Transport Measures

Public Transport (PT) measures usually pertain to exclusive bus lanes and/or priority measures at intersections. In the case of Thessaloniki PT measures refer to the implementation of an additional bus lane at the area where one of the tunnel ramps exits. This particular lane starts at the city centre as a contra flow lane and continues as a standard bus lane. The measure is proposed only in combination with the new road infrastructure, but it is examined separately.

Complementary Measures: Traffic Light

A new UTC system has been recently installed in the area of Thessaloniki by SIEMENS. The system covers the whole area i.e. both the units belonging to the Ministry and the ones belonging to the Municipalities. The new UTC will choose the most appropriate programme depending on the traffic and weather conditions from a library of proactive plans. A new base time setting has been already set which replaced all old time settings. Traffic signal progression remains and strengthens wherever possible. Some time allocation changes at individual units also took place. All the above changes have been taken into account in the examined scenarios.
The following cases were defined:

A The 1996 SATURN calibrated and validated network.

B The 2005 Reference Case based on the expected network for 2005 as well as the expected Trip Matrix for the same year. The 2005 Trip matrix forecast is based on the long term trend of traffic increase in the area of Thessaloniki. Different rates for the various traffic zones were taken according to the recorded demographic expansion, averaging in a value of 5% for the whole study area. This figure is lower by 2.9 percentage units from the value of 7.9% per year observed for the period 1989-1996.

C Construction of the new tunnel arterial - anticipated for year 2005.

D Construction of the Metro Line, also anticipated for year 2005; this case differs from the previous ones in terms of the Trip matrix, since a modal change is expected to take place once the metro is in operation. There are no major changes between the network used in Reference Cases C and D. The diversion rates used for the Metro scenario come from a specific modal split model constructed for the purposes of the Thessaloniki Metro Demand Forecasting study[13].

All model runs were for the morning peak period. Fixed demand for private car trips was taken and Public Transport supply was assumed unchanged with the implicit hypothesis that it can accommodate additional patronage in the cases where modal shift is expected (i.e. PT promotion measures).
Different groups of TDM packages were created and tested, viz:

- **TDM1** refers to major pedestrianisation in the city centre area.
- **TDM2** refers to Public Transport promotion measures (additional bus lanes) combined with traffic calming measures in the city centre; the latter takes the form of main street narrowing and reduction of speed limit along these streets.
- **TDM3** refers to the previous measures plus some changes in the directions of certain roads and better parking management along these roads.
- **TDM4** refers to traffic calming only.
- **TDM5** refers to the tolling of the new arterial tunnel.

The relationship between scenarios and Cases/TDM packages is shown in the following table.

[13] Thessaloniki Metro Demand Forecasting study, Phase I and Updates, Wilbur Smith Associates and TRIAS SA Consulting, 1994-1996

Scenario	Case/TDM Package	Explanation	Year
-	Reference Case A (RCA)		1996
0	Reference Case B (RCB)	Minor network changes	2005
1	Reference Case C (RCC)	New infrastructure (Tunnel)	2005
2	Reference Case D (RCD)	New infrastructure (Tunnel + Metro)	2005
3	RCC + TDM1	Tunnel + TDM1	2005
4	RCC + TDM2	Tunnel + TDM2	2005
5	RCC + TDM3	Tunnel + TDM3	2005
6	RCD + TDM1	Tunnel + Metro +TDM1	2005
7	RCD + TDM2	Tunnel + Metro +TDM2	2005
8	RCD + TDM3	Tunnel + Metro +TDM3	2005
9	RCC + TDM4	Tunnel + TDM4	2005
10	RCC + TDM5	Tunnel + TDM5	2005

Tab. 52 – Scenarios in Thessaloniki

5.7.3 Data

The data available for both the city of Thessaloniki and the Thessaloniki Greater Area (TGA) mainly come from major or smaller studies and from periodic measurement programmes launched by certain authorities. A lot of data are also available from University sources, but they are not always compatible with the other data. The most important of them are the following:

OD Matrix

The existing OD matrix is based on the 1988-1989 Household Survey and covers the whole TGA area. The survey consisted of approximately 10,000 household interviews, from which trip characteristics were obtained for approximately 40,000 trips. The trip purpose classification is: work, return to home, education, recreation, personal business, other.
The OD Data Base was calibrated by data from Road Side Interviews and traffic counts along cordon and screen lines. Some additional surveys (buses, lorries, school buses, taxis) also took place con-currently with the main OD survey. AM, PM and 24hour matrices are available.
The existing Data Base allows for the building of both aggregate and mode based OD matrices. Load factors per mode are also available. Grouping of zones is also possible, using a special computer program, developed by TRIAS SA.
The modes available in the Demand Matrix are: car, taxi, bus, lorry, motorcycle, PT bus, pedestrian.

Public Transport (Bus) Patronage Data

These data include passengers per line and per month for the years 1992 and 1994. Data are based on the tickets sold on-board or validated on-board. Samples for the patronage variation over time within the day time are also available for 1992. Total figures per month by bus routes or all years are also available.

Bus and Private Car Journey Times

Bus journey times for selected bus routes are available for years 1993, and 1995. The data selected include run time, boarding and alighting time as well as delays at major signalised intersections. Recent journey times for private cars are also available for some 20 main routes.

Traffic Counts

Traffic counts are available for a number of locations in the city of Thessaloniki, by the Municipality of Thessaloniki (1995). Detailed counts exist for 125 turning movements at about 35 locations.

Traffic flow data (24 hour) also are available for 3 or 4 periods per year on selected locations, by the Ministry of Environment, Planning and Public Works.
New traffic data were also obtained from a major traffic count programme in autumn 1996, for the purposes of a major traffic study. These counts pertain to some 35 intersections for 15 hour periods within typical week days.

Stated Preference Survey

These data comprise state preference and stated intentions data for two main groups: Public Transport and Private car / Taxi users. The survey was carried out in 1993 and it dealt with a Metro Line which is planned to be constructed in the city of Thessaloniki. Additional data are available from an SP survey carried out in 1995 regarding Public Transport services. More SP interviews are planned for the near future by TRIAS SA and EuroTrans Consulting Ltd.

5.7.4 Modelling Framework

The modelling framework is illustrated in the following figure.

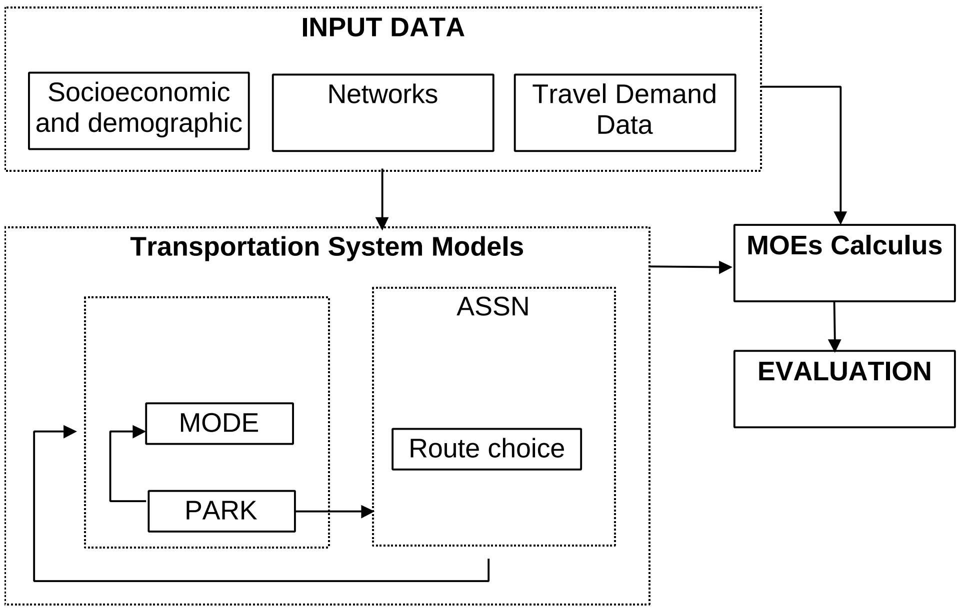


Fig. 53 – Thessaloniki modelling framework.

The model system comprises:

- SATURN Simulation/Assignment model calibrated for 1996, and
- Metro (Public Transport) Demand Forecasting Model based on SP data and an aggregate Logit mode choice model.

The mode choice model is an aggregate Logit model based on SP data. The SP data comprises 268 valid interviews with travellers in Thessaloniki (137 Public Transport users and 131 Car and taxi users).
The SP survey technique adopted a ranking method with fractional factorial experimental design including the following variables:

- Cost
- Time
- Mode (Car vs. PT)
- Transfer between PT modes

The SP data survey produced relevant mode-specific constants, alternative-specific constants, utility coefficients for travel time and travel costs and associated Values of Time. In particular the following results were found:

- The value of time for bus passengers is between 1.05 - 1.15 ECU per hour (in 1997 prices).
- The value of time is 2.55 ECU per hour per car (including the effect of car occupancy) in 1997 prices; a SP survey in Athens in 1997 gave a VoT of 3.2 ECU per hour per car; another SP survey in Athens in 1996 gave a weighted average VoT for all modes of transport of 1.85 ECU per hour per passenger.
- The Metro Mode Constant was estimated to be equivalent to 15 minutes of journey time or to 0.3 ECU, in 1997 prices. In other words, for the same journey time by Metro, existing bus passengers would be prepared to pay an extra 0.3 ECU to use the Metro instead of bus, purely for the comfort, convenience, reliability and image offered by the Metro. Alternatively, for the same fare as bus they would be prepared to take an extra 15 minutes by Metro rather than go by bus, again simply on the grounds of the Metro level of service presented to the respondents compared to the current bus service as known by the user.
- The impact of a transfer between PT modes was estimated as equivalent to 10 minutes or 0.18 ECU. Another SP survey in Athens gave a value of 0.32 ECU for the equivalent cost of a transfer in 1996.

The utility coefficients and constants were used in a Logit model to calculate, in an aggregate way, the potential diversion from car to public transport in the case of the scenarios involving the introduction of the proposed Metro line (with Case D, Scenarios 6, 7 and 8). The catchment area of the proposed Metro line was defined according to the radius from each of the 14 proposed Metro stations (500 m walking distance) and the car trips were split into tree categories, viz:

- A. both ends within the catchment area
- B. one end within the catchment area
- C. no end within the catchment area

The output diversion rates from the mode choice model varied according to the above trip types: 6.6% for Type A, 2.7% for Type B and 0% for Type C during a 24-hour period. Given that the requirement here was for peak-hour analysis and the journey times of the Metro are expected to be more competitive compared to car journey times during the peak, the peak-hour weighted average diversion rate from private car to Metro public transport was found to be 9.8%. The diversion rates output from the mode choice model were applied to the SATURN peak-hour trip matrix by matrix factoring according to the appropriate matrix cell groups.

5.7.5 Results from modelling

Following tables and chart report the simulation results for each scenario, in terms of travel time (vehicle*h, subdivided according to queued time and cruise time), other network performance and pollutant indicators.

	RMB *SCE 0*	RMC *SCE 1*	RMD *SCE 2*	RMC+TD1 *SCE 3*	RMC+TD2 *SCE 4*	RMC+TD3 *SCE 5*
Transient queues (pcuhr/hr)	-	-8.01	-9.37	-8.19	-7.86	-7.33
Over-capacity queues (pcuhr/hr)	-	-35.37	-36.63	-35.22	-35.17	-35.22
Link cruise time (pcuhr/hr)	-	-1.04	-1.96	-1.13	-1.03	-0.95
Total travel time (pcuhr/hr)	-	*-23.73*	*-24.92*	*-23.68*	*-23.59*	*-23.55*
	RMD+TD1 *SCE 6*	RMD+TD2 *SCE 7*	RMD+TD3 *SCE 8*	RMC+TD4 *SCE 9*	C+TD5 *SCE 10*	
Transient queues (pcuhr/hr)	-10.44	-10.48	-9.47	-7.64	-0.03	
Over-capacity queues (pcuhr/hr)	-36.62	-36.75	-36.76	-35.33	-0.32	
Link cruise time (pcuhr/hr)	-2.10	-1.95	-1.84	-1.08	-0.04	
Total travel time (pcuhr/hr)	*-25.06*	*-25.11*	*-24.98*	*-23.68*	*-0.22*	

Tab. 54 – Percentage results of travel time indicators: comparisons to base reference case B (SCE 0)

On the basis of the modelling results the following conclusions can be drawn.

- In cases of high urban density and inadequate transport system with associated severe congestion and environmental problems, such as in Thessaloniki, there is a need for new transport infrastructure in combination with TDM measures, in order to maximise the effects of the TDM measures.
- The aggregate mode choice model, although useful as a broad-brush approach, is not sensitive enough to investigate impacts from marginal changes in the level of service and particular generalised costs of private and public transport; a disaggregate model system would be far more appropriate for testing the impact of relevant TDM measures on mode choice (e.g. bus lanes).
- The analysis concentrated on peak-hour, but benefits of TDM measures can be also in the inter-peak and even in the off-peak; any peak-spreading impacts of TDM measures will have to be also assessed. The addition of departure time choice, destination choice and trip frequency choice in a disaggregate model system would be most appropriate and relevant, including peak-spreading analysis.

The results indicate that the infrastructure creates much more significant impacts on traffic, the environment and on energy consumption than the packages of TDM measures alone or even in packages. The evaluation made was qualitative. Sensitivity tests were also performed.

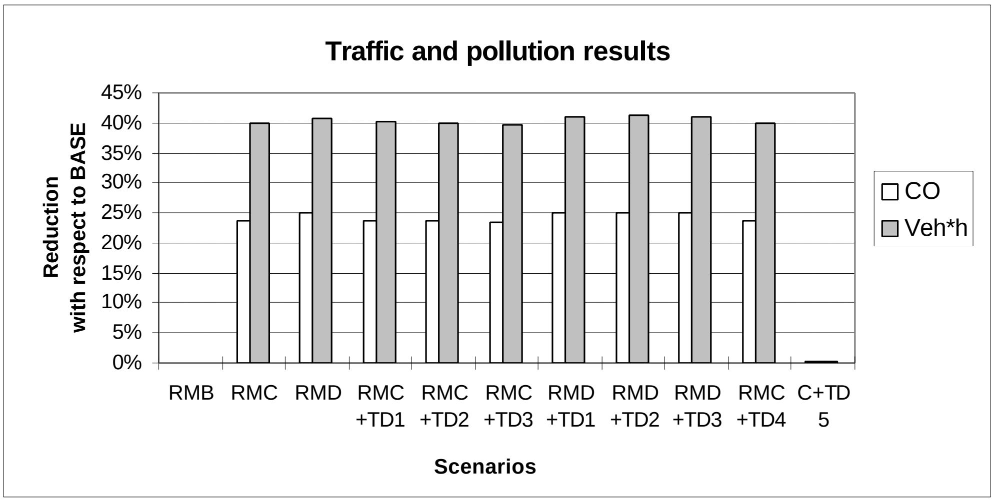


*Fig. 55 - Vehicle*h results compared with reduction of CO emissions (percentage with respect to base reference B)*

The overall conclusion is that in cases such as Thessaloniki, where major traffic problems exist, the implementation of the TDM measures examined have rather minor effects, unless they cover an extensive area. In any case the impacts on traffic are not so significant. In evaluating these impacts it is necessary to incorporate benefits to the pedestrians and to inhabitants as well. On the other hand the impacts of long term measures is much more sound and if combined properly with innovative or other TDM measures can be of importance.

5.8 Geneva (CH)

5.8.1 Test Site Description

Switzerland is a confederation of political units called “Cantons”. Geneva belongs to the “Canton de Genève” which comprises mostly the city of Geneva and its suburbs in a range of about 10 km from downtown (the Canton area is 282 km^2). About 400,000 people live in the Canton de Genève (and 174,000 in the city itself) while 200,000 persons commute daily from Swiss and French neighbour regions to Geneva. Population density is about 2213 inhab./ km^2 for the city and 1418 inhab./ km^2 for the whole Canton. Geneva is located on the Rhône River at the end of the Lake Leman. The size of the city is relatively small since it is surrounded by the Lake Leman and the French border.

It is hosting many international organisation (OMS, ONU, ILO, International Red Cross, etc.), one university (University of Geneva) and many head-quarters. Many banks and luxury shops are also located in Geneva. There is a main railway station (Cornavin) in the city centre with a high speed train to Paris and SBB (Swiss) trains and an international airport (Cointrin) located nearby with a direct rail link to the main station.

The main components of its road network are the radial roads converging towards the CBD (Central Business District), the main bridges (Pont du Mont-Blanc) over the Rhône and several bridges over the Arve River. There is a ring road which provides access to France, Geneva airport and, further on, to Lausanne and the rest of Switzerland. The highway ring road which was part of C2000 (see below) is now completed and operational on the Swiss part (part of the Ring is on French territory). This ring helps to avoid trough traffic and reduce congestion in Geneva; however, its access from Geneva CBD is often difficult. From a car user perspective, the access from one side of the lake to the other is not easy (this has justified the idea to construct a bridge over the Lake Leman - see below).

The current public transportation system consists of two streetcars transit lines and about twenty buses or trolley buses lines that deserve Geneva and its suburbs with connection to the regional network. Streetcars, buses and taxis (there are about 500 taxis) can partially use reserved lanes and an area in the CBD that is forbidden to the cars. A new light rail line is under project as well as accompanying measures (traffic calming).

The most recent city-wide transportation plan (so-called “C2000” for road planning and “TC2000” for public transportation planning) is under implementation since 1992 and far from completed. It aims to improve air quality in the city, increase mobility and public transportation availability and improve the accessibility of key locations. Like in other Swiss cantons any major political decision may be the object of a public poll. As a matter of fact C2000 was relying strongly on the construction of a new crossing bridge over the Lake (with a cost of about 250 KECU). After a difficult campaign residents have recently (June 1996) rejected the construction of this bridge.

The daily modal split within the canton of Geneva is as follows: 20% of all trips use public transportation, 50% use private vehicles and the remaining are pedestrians. From our survey administered in Geneva the average travel time is about 22 minutes for private cars and 28 minutes for public transport.

Transportation planning at the cantonal level is the responsibility of the “Office des Transports et de la Circulation” (Transportation Office), division of the “Département de Justice et Police” (Justice and Police Department) while the “Département des Travaux Publics et de l’Energie” (Public Works Department) is responsible for the building of new infrastructures. Case studies, evaluation of transport policies, prospective and other projects concerning transport planning are often subcontracted to local transportation consulting companies (such as to Transitec, to the Bureau Blaise Dériaz and to CITEC among others).

5.8.2 Scenarios

This section summarises the TDM measures that have been envisaged on the Geneva test site, ranked according to the AIUTO consortium classification.
Table 56 presents the list of TDM packages and the relevant TDM measures as well as their applicability. Note that for this test site, TDM packages consist mainly in one or two TDM measures.

TDM package	Description	Applicability
Package I Traffic calming	Zones 30 km/h, lanes reduction in favour of TC	CBD
Package II Pedestrianisation	Square given to the pedestrians in the CBD, parking installation	CBD
Package III Access control	CBD access regulated, traffic lights measures, through traffic control	Small ring around the CBD, radial arteries.
Package IV Staggered and flexible activity times	Staggered (IV a) and flexible (IV b) hours	All commuters city-wide
Package V Fuel pricing	Fuel pricing, redistribution	All commuters city-wide
Package VI Combination of measures and evaluation of the induced demand	Staggered hours, flexible hours and fuel pricing	All commuters city-wide

Tab. 56 - Proposed TDM packages.

Package I: Traffic Calming

This package consists of the reduction of the number of private transport lanes on two main radial streets in the CBD. The freed lanes are given to a new streetcar. An additional measure is to integrate the “Carl-Vogt” Boulevard in the 30 km/h zone that it belongs to.

Road name	***Length (km)***	***before***	***after***
Rue de Lausanne	0.960	2x2 lanes	2x1 lane
Avenue des Acacias	1.330	2x2 or 3 lanes	2x1 lane
Boulevard Carl-Vogt	1.150	1 lane, 50 km/h	1 lane, 30 km/h

Tab. 57 – Traffic calming

Package II: Pedestrianisation

The aim is to suppress the traffic that goes through a city square called “Place Neuve” by giving it to pedestrians. This square is an important traffic centre in the CBD with the presence of the university, the conservatory and various cultural buildings (theatres, cinemas, etc.). A complementary project of digging a parking under the square was submitted as a complementary measure to maintain a sufficient accessibility.

Package III: Access Control

This package consists of the reduction of the capacities by 50% during the most congested hours of the morning peak of about 20 radial roads which are major access roads to the CBD. This measure aims to use traffic lights control to regulate the number of vehicles entering in the CBD during the peak hour. These temporary reductions of capacity would have the effect of keeping the queuing vehicles at the CBD boundary while maintaining good traffic conditions in the CBD.

Moreover this would tend to the spread the morning peak hour. This measure would also help to reduce the morning peak CO emission in the CBD.

Package IV: Staggered Activity Times

The *staggered* hours are defined by the fact that *different* commuters have different work starting hours (or different work starting periods).
The *flexible* hours are defined by the fact that the employer allows an *individual* commuter to start working between a given time period instead of a fixed hour.
Two different types of temporal flexibility have been studied to evaluate the potential benefit of such measures:

- IV a: Staggered hours: the distribution of start working hours is further spread around the morning peak (t* distribution).
- IV b: Flexible hours: each individual driver is allowed a wider no-penalty arrival period (Δ) but the starting hours distribution (t*) remains identical.

Note that in practice both measures would be combined but we intend here to analyse their impact separately. These measures were applied to all morning commuters.

Package V: Fuel Pricing

Simulations of fuel pricing have been modelled by changing the cost value of time of individual drivers (α). By doing this we assume that during the morning peak fuel consumption is roughly proportional to the total travel time. This measure was applied to all morning commuters.

Package VI: Combination of Measures and Induced Demand Evaluation

This package is not a part of the initial TDM measures. Instead, it combines the TDM of Packages IV and V and takes into account elastic demand. It has been suggested that these measures would essentially change the level of demand, which justifies the motivation to do so.

5.8.3 Data

The B. Dériaz office, a local transportation office, kindly provided us with the transportation data available for the city of Geneva. It consists of an EMME/2 database:

- The network: 3000 links describe the Geneva network and the surroundings regions. Each link is characterised by standard parameters: length, maximum speed (or free flow travel time), capacity and a volume-delay congestion function.
- The nodes, which are either intersections, or intermediary points on the links.
- The centroids (a centroid can be an origin or a destination): the city and suburbs are divided into 280 zones.
- The OD matrices (the OD matrix we used was estimated for the morning peak).

The Transportation Office provided us with traffic counts. The road usage for the main arterial roads in Geneva has been recorded for whole day periods and at different period of the year. There are two types of counters: about 20 fixed traffic counters and several mobile traffic counters. These data together with other observations were used to partially calibrate the model.
Socio-economic data are available from the Cantonal Office for Statistics (a survey is conducted on the whole population each nine years in Switzerland) and a survey (micro-census) is administered each three years to a few thousand individuals. The micro-census is more focused on specific transportation issues (such as travel diaries). Finally, various specific surveys have been conducted by private firms (but they are of little use) and by the University of Geneva.

5.8.4 Modelling Framework

The dynamic simulation framework adopted in this study is displayed on Figure 58 (for the inelastic demand case) and Figure 59 (for the elastic demand case). The major differences between the dynamic scheme we propose and the general framework rely in the fact that the general framework is mostly a static scheme, in the sense that the classical hierarchical structure of the four-steps planning is mirrored directly into the travel choices modelling. That is, travel choices concerning destination, departure time, mode and/or parking are performed *before* the assignment, which means that itinerary choices are hence disjointed from the other travel choices. On the opposite, in the dynamic approach, all the travel choices are bound in a tight closed loop, whether it is departure time, route or mode choice. Even if the order in which choices are performed remains the same for an individual, one cannot neglect the fact that, in a dynamic context, some users might revise some of their travel choices according to the driving conditions experienced *en-route* or according to *information.* One might be tempted to keep the hierarchical structure of Figure 58 for medium to long term planning but even so, the closed loop of within-day interactions between the travel choices is preferable for the evaluation of *intelligent travel systems (ITS).*

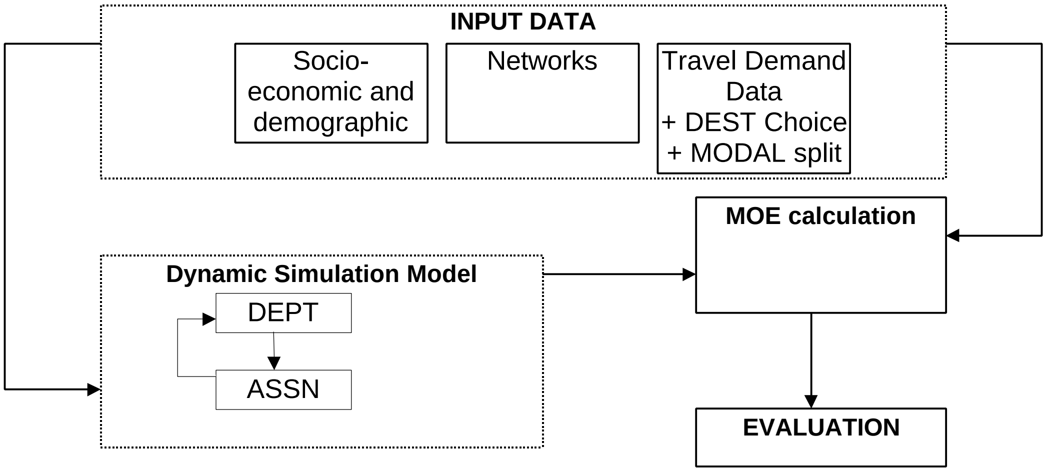


Fig. 58 - Dynamic Simulation Scheme with fixed *auto demand*

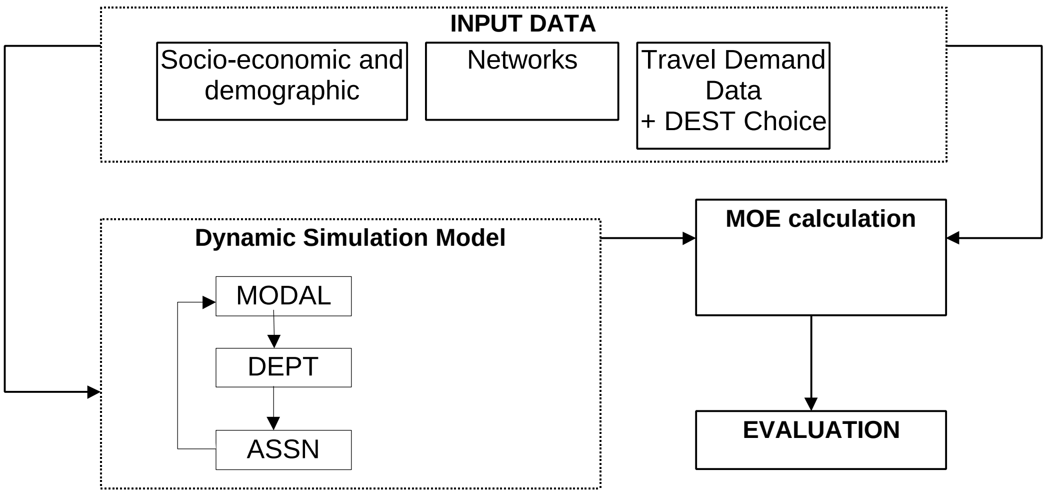


Fig. 59 - Dynamic Simulation Scheme with elastic *auto demand*

5.8.5 Results from Modelling

Experiments showed that for local policies and in particular for traffic regulation or traffic calming (see Package I, II and III), the impacts on road usage and on itinerary diversion were mild. We believe that those impacts are over-estimated in the static approach. On the contrary, even local traffic regulation like access control (see Package III) can have a substantial impact on departure time choice. This is even more important for TDM measures involving changes in the activity

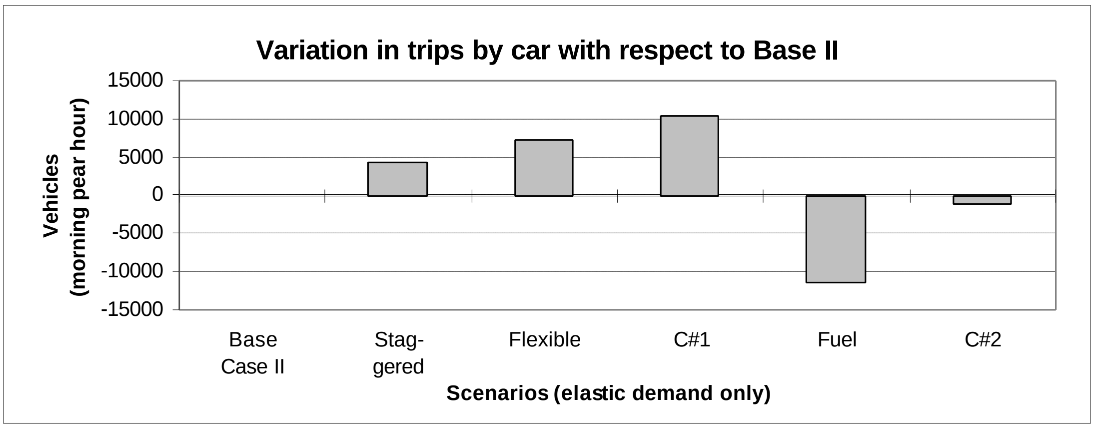
schedules (see Package IV, V and VI). Note that we set a medium importance to route choice, not that its modelling should be discarded at all, but to stress out that somehow, the impacts due to departure time changes might be more important for some of the TDM's.
Again, our experience suggests that the morning peak shape is more elastic to departure time changes than to itinerary modifications and that consequently, the users' travel cost can be largely affected by departure time changes as well as activity schedules changes.
Following tables and charts report the main evaluation results, both with the inelastic and the elastic demand.

	Units	Base Case I	Acc. Control	Staggered	Flexible	Fuel
Network indicators						
Car trips	[-]	80068	0.0%	0.0%	0.0%	0.0%
Congestion Index	[-]	0.3	0.8%	-24.0%	-19.9%	-4.3%
Travel Time	[min]	22.8	0.2%	-9.0%	-7.5%	-2.1%
Time variation indicators (staggered activities)						
Prop. of Early Arrivals	[%]	0.21	0.2%	-7.3%	-52.0%	9.6%
Prop. of Late Arrivals	[%]	0.27	1.4%	-16.3%	-19.7%	-0.4%
Prop. of On-Time Arrivals	[%]	0.52	-0.8%	11.6%	31.3%	-3.7%
Average Early Delay	[min]	16.72	0.2%	-25.4%	1.9%	11.7%
Average Late Delay	[min]	7.74	2.3%	-10.6%	12.8%	0.5%

Fig. 60 - Results, scenarios with inelastic demand

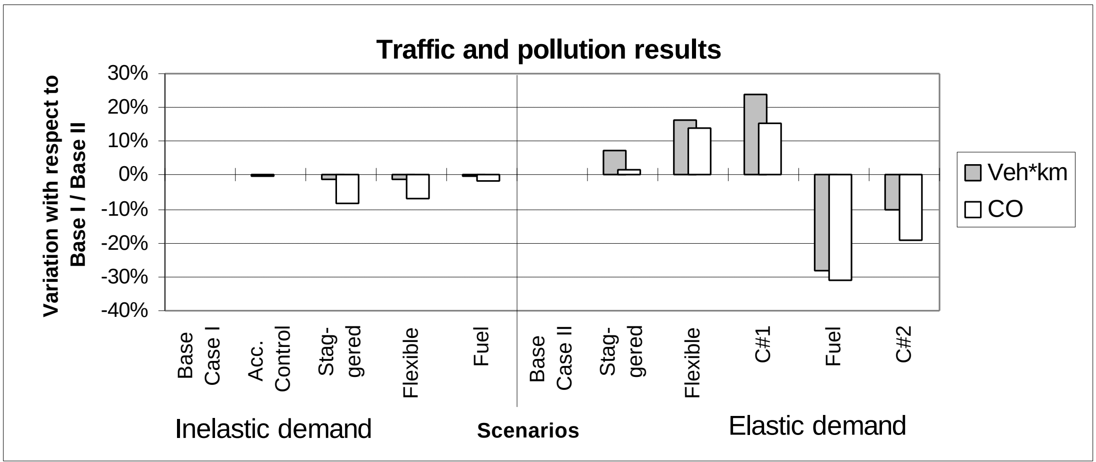
MOEs	Units	Base Case II	Staggered	Flexible	C#1	Fuel	C#2
Network indicators							
Car trips	[-]	80621	5.4%	9.0%	12.8%	-14.2%	-1.5%
Congestion Index	[-]	0.3	-20.4%	-7.4%	-22.9%	-23.0%	-41.4%
Travel Time	[min]	18.43	-4.4%	4.4%	1.4%	-20.3%	-19.3%
Time variation indicators (staggered activities)							
Prop. of Early Arrivals	[%]	0.18	0.6%	-50.5%	-55.4%	2.3%	-56.5%
Prop. of Late Arrivals	[%]	0.28	-20.9%	-10.3%	-24.1%	-15.1%	-37.6%
Prop. of On-Time Arrivals	[%]	0.54	10.7%	22.1%	30.9%	7.2%	38.3%
Average Early Delay	[min]	7.71	-17.9%	16.5%	4.2%	-12.3%	-9.5%
Average Late Delay	[min]	8.23	-22.4%	19.3%	10.7%	-31.5%	-23.1%

Fig. 61 - Results, scenarios with elastic demand

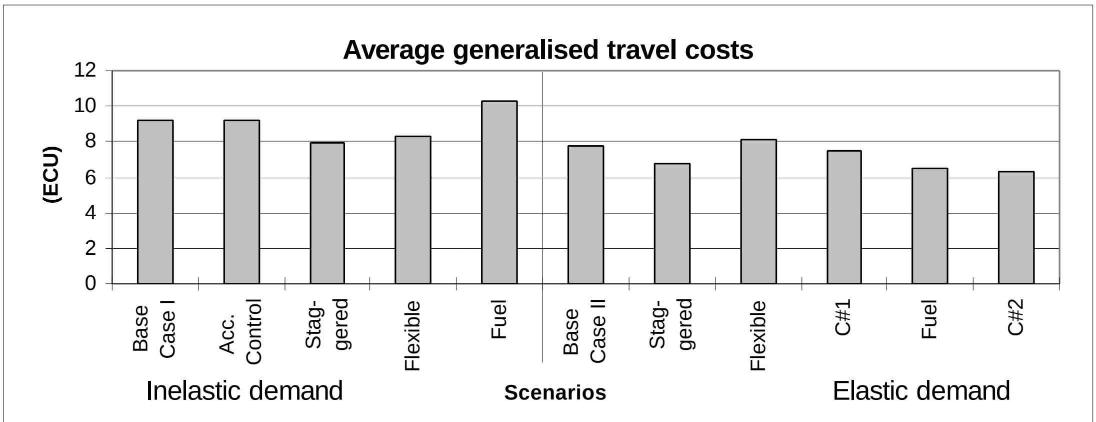


Tab. 62 - Car trips results: variation in the number of car trips for scenarios with elastic demand, with respect to Base II

The result of the measures of access control are small because people scale the departure times. On the contrary, the more sensible effects are due to the interventions on the working time (staggered hours or flexible hours) because of the sensible decrease of the travel cost (0.3-0.6 ECU): the staggered hours (variability of the working time among companies) seem to dominate the flexible ones (flexibility of the beginning time for the workers).
There are also some scenarios where the combination of more TDM has been applied (staggered + flexible, staggered + flexible + fuel pricing). A synergetic indicator has not been studied, but at first sight the effects seem to be superadditive.
The experiments on the Geneva test-site lead to a main conclusion: *the potential benefits from TDM's that are likely to change activity times, tour frequencies or tour patterns, are of the same order of magnitude that benefits that can arise from major infrastructure changes*. This conclusion is particularly meaningful in the framework of AIUTO, since the project aimed to precisely address innovative "flexible and reversible" measures.



*Tab. 63 - Vehicle*km results and CO emissions (percentage variation with respect to Base I and Base II, respectively)*



Tab. 64 - Economic results: global average generalised cost

The results exhibited by the dynamic traffic simulator provide complementary results with respect to those of the static approach simulated in other test sites. MOE's show that, for flexible and staggered hours, changes in the private mode could be drastic: roughly, for an extended flexibility of 10 min, the congestion indexes can be decreased by 10%. These figures suggest that the study of such TDM's and their implementations cannot be regarded as "complementary" (secondary) measures.
The use of dynamic models brought also new insights even for the implementation of classical TDM's like traffic regulation by access control. An experience of ring-shaped access restriction showed that, while the classical approach predicted an increase of alternative routes and,

consequently, of the car network, the dynamic approach predicted almost no change in the road usage, but small changes in the temporal traffic patterns. That is, instead of facing longer routes (thus more expensive routes), commuters preferred to internalise the queue waiting time by arriving a little bit earlier or later at work. This important result also demonstrated that innovative tools can also bring important analysis results in classical supply-oriented TDM's: from the recommendation point of view, we emphasised the analysis of time-related policies that promise to be quite resourceful in terms of city-wide benefits.

6. ASSESSMENT OF THE MODELS

6.1 A priori Hypotheses on Modelling Requirements

Hypotheses on modelling requirements essentially deal with the following two aspects:

- the indicators that the model has to evaluate, for each TDM measure;
- the demand choices that the model has to consider, for each TDM measure.

Within the AIUTO project, a first *a priori* estimate of such requirements was made and is reported in the following tables 65 and 66.
The recommendation for investigating relations between TDM and indicators/demand choices has been expressed in a qualitative way, in the form of a three-level scale: low/medium/high (L/M/H).

TDM Measures			***Indicators to be evaluated (group of indicators)***						
			Air pollution	Noise pollution	Energy saving	Functionality of the whole system	Financial	Accessibility	Equity
Main measures	Innovative Supply System	Park and Ride	M	M	M	H	M		
		Car Pooling	M	M	M	H			
		Dial-a-Ride	L	L	L	M		H	H
		Card op. cars	M	M	L	L			
	Pricing Measures	Road pricing	M	M	M	H	H	H	H
		Parking pricing	L	L	L	H	H	H	M
		PT fare structure	M	M	M	M	H	L	L
	Regulation Measures	Access control	H	H	M	H		H	L
		Parking management	L	L	L	H		H	M
		Traffic calming	M	H		L		L	L
		Pedestrian and cycling	H	H	H	H		H	
		PT measures	M	M	M	M		M	
Complementary measures		HOV priority	M	M	M	M		H	H
		Traffic lights	L	L	L	H		M	
		Variable msg. Signals	L	L	L	H		L	L
		Ramp metering	L	L	L	L			
		Regulation enforcement	L	L	L	H	M	H	H
		Staggered activity time	M	M	M	H		M	

H: the estimate and the evaluation is high recommended
M: the estimate and the evaluation is medium recommended
L: the estimate and the evaluation is low recommended
Empty: it was not possible to estimate the level of importance (a priori)

Tab. 65 - Relation between TDM's and indicators to be evaluated

6.2 Modelling Requirements from Each Test-Site

Results from test sites are presented below. For the test site versions, the above mentioned three-level classification has been reduced into a two-level one, with symbols **+** (very relevant) [corresponding to H or M] and **-** (less relevant) [corresponding to L]. Blank cells reflect measure-indicator pairs or measure-choice pairs that were not considered. It should be noted that these tables state what has been really considered by the modelling, rather an a priori expectation.

TDM Measures			Demand choices to be investigated						
			Assignment (route choices)	Departure time choices	Mode	Destination	Activity time	Trip frequency	Tour pattern
Main measures	Innovative supply system	Park and Ride	H		H				L
		Car Pooling	H	M	H				
		Dial-a-Ride	H		M		H	H	M
		Card op. cars	M		H	L	L		
	Pricing measures	Road pricing	H	M	H		H		
		Parking pricing	H		H	H	H	L	
		PT fare structure	H				L		
	Regulation measures	Access control	H	M		M	L		
		Parking management	H		H	M	L	L	
		Traffic calming	M		H	H	L		L
		Pedestrian and cycling	H		H	L			
		PT measures	H		H		L	L	
Complementary measures		HOV priority	H		H	H			L
		Traffic lights	H						
		Variable msg. Signals	H		H				
		Ramp metering	H		L				
		Regulation enforcement	H		H				
		Staggered activity time	H	M	M	L			

H: the estimate and the evaluation is high recommended
M: the estimate and the evaluation is medium recommended
L: the estimate and the evaluation is low recommended
Empty: it was not possible to estimate the level of importance (a priori)

Tab. 66 - Relation between TDM's and demand choices

6.2.1 Como

The Como demand model does not have the capability to predict changes in activity time, trip frequency and tour pattern, and the noise indicator was not taken into account.
A low impact is found for Dial-a-Ride service on accessibility and equity indicators; furthermore, public transport service improvements tested in Como are almost irrelevant for all the considered indicators.

TDM Measures			Evaluated indicators (group of indicators)						
			Air pollution	Noise pollution	Energy saving	Functionality of the whole system	Financial	Accessibility	Equity
Main measures	Innovative supply system	Car Pooling	+		+	+	-		
		Dial-a-Ride	-		-	-	-	-	-
	Pricing measures	Road pricing	+		+	+	+	+	+
		Parking pricing	+		+	+	+	+	-
	Regulation measures	PT measures	-		-	-		-	-

TDM Measures			Investigated demand choices						
			Assignment (route choices)	Departure time choices	Mode	Destination	Activity time	Trip frequency	Tour pattern
Main measures	Innovative supply system	Car Pooling	-		+				
		Dial-a-Ride	-		-	-			
	Pricing measures	Road pricing	+	+	+	+			
		Parking pricing	-		+	+			
	Regulation measures	PT measures	-		-		-		

+: modelled and very relevant
-: modelled and less relevant
Empty: not modelled

Tab. 67 - Como

As expected, this table shows that mode and destination choices are affected by both road and parking pricing measures whereas route choice is influenced mostly by road pricing. The public transport measures do not seem to have a significant effect on any travel choice, whereas the car-pooling measure does affect mode choice, as expected.
The results indicate that:

- changes in air pollution, fuel consumption and financial aspects are primarily attributed to mode changes;
- financial aspects are mostly related to the modal shifts;
- accessibility and equity are related mostly to destination choice.

6.2.2 Salerno

In Salerno, the financial effects of TDM measures were not taken into account. All the other evaluated impacts agree with the original table.
Only route, mode and destination choices were modelled in Salerno. It can be observed that the route and mode choices are significantly affected by access control measures. In general, all the TDM measures analysed seem to have a significant effect on mode and route choices but not on destination choice.

TDM Measures			Evaluated indicators (group of indicators)						
			Air pollution	Noise pollution	Energy saving	Functionality of the whole system	Financial	Accessibility	Equity
Main measures	Innovative supply system	Park and Ride	+	+	+	+		-	-
	Pricing measures	Parking pricing	-	-	-	+		+	+
		PT fare structure	+	+	+	+		+	+
	Regulation measures	Access control	+	+	+	+		+	+
		Parking management	-	-	-	+		+	+
		PT measures	+	+	+	+		+	

TDM Measures			Investigated demand choices						
			Assignment (route choices)	Departure time choices	Mode	Destination	Activity time	Trip frequency	Tour pattern
Main measures	Innovative supply system	Park and Ride	+		-	-			
	Pricing measures	Parking pricing	+		+	-			
		PT fare structure	-		+	-			
	Regulation measures	Access control	+		+	+			
		Parking management	+		+	-			
		PT measures	+		-	-			

Tab. 68 - Salerno

In Salerno, departure time choice, activity time choice and tour pattern were not modelled. On the other hand, the parking dimension (i.e., parking type and location for car trips, and park and ride for public transport trips) was taken into account. The significant impacts seems to be the influence of parking location and type on financial aspects, accessibility and equity. The route choice model has a significant influence on all the indicators and the destination choice seems not to have a significant effect on any of the MOE’s.

6.2.3 Randstad

Noise and energy saving impacts were not analysed. Furthermore, a departure time choice model was not included while an activity time-period (peak vs. off-peak) model was. All the envisaged TDM measures have minor effects on air pollution. However, since only a cursory overview of air pollution was possible, no significant conclusions can be drawn about the effects of the studied TDM measures.

TDM Measures			Evaluated indicators (group of indicators)						
			Air pollution	Noise pollution	Energy saving	Functionality of the whole system	Financial	Accessibility	Equity
Main measures	Pricing measures	Road pricing	-			+	+	+	+
		PT fare structure	-			+	+		-
	Regulation measures	Access control	-			+		+	+
		Parking management	-			+		+	
		Traffic calming	-			-		-	-
		PT measures	-			+		+	
Complementary measures		HOV priority	-			+		+	+
		Traffic lights	-			+		+	
		Variable Msg. Signals	-			+		-	-

TDM Measures			Investigated demand choices						
			Assignment (route choices)	Departure time choices	Mode	Destination	Activity time	Trip frequency	Tour pattern
Main measures	Pricing measures	Road pricing	+		+	+	+	+	-
		PT fare structure	-		+	+	-	+	-
	Regulation measures	Access control	+		-	+	-		-
		Parking management	+		+	+	+	-	-
		Traffic calming	+		+	+	-		-
		PT measures	+		+	+	-	-	-
Complementary measures		HOV priority	+		+	+			-
		Variable Msg. Signals	+		-	+	-	-	-

Tab. 69 - Randstad

In the Randstad study, the impacts of the different policy measures are generally lower on mode choice and higher on destination choice than assumed in the a priori table. These findings indicate the heterogeneous character of the relatively large study area. The activity time choice was only modelled for car-driver journeys: that is why the non-road-based measures have no significant effect on activity time.
We note the high relevance of the assignment model as well as the activity time choice (modelled only for car-driver journeys). On the other hand, the tour pattern choice seems not to influence any indicator except the functionality.

6.2.4 York

Policy measures in the York test site were designed to affect route choice behaviour. The emphasis of the York study was on the assignment model and thus on route choice and network performance.

TDM Measures			***Evaluated indicators (group of indicators)***						
			Air pollution	Noise pollution	Energy saving	Functionality of the whole system	Financial	Accessibility	Equity
Main measures	Innovative supply system	Park and Ride	+			+			
Main measures	Regulation measures	Access control	+			+		+	+
Main measures	Regulation measures	PT measures	+			+		+	+
Complementary measures		HOV priority	+			+		+	

TDM Measures			***Investigated demand choices***						
			Assignment (route choices)	Departure time choices	Mode	Destination	Activity time	Trip frequency	Tour pattern
Main measures	Innovative supply system	Park and Ride	+						
Main measures	Regulation measures	Access control	+						
Main measures	Regulation measures	PT measures	+						
Complementary measures		HOV priority	+						

Tab. 70 - York

The York model only includes the route choice dimension. In the York analyses, departure time, mode and destination choices are assumed to be fixed. The focus of the York evaluation is on route choice and network performance modelling.

6.2.5 Thessaloniki

The Thessaloniki test site also evaluated major capital projects (i.e. a new metro line and a new tunnel). These measures, and particularly the new metro, affect significantly the considered indicators. The noise and equity indicators were not taken into account. A low impact was found for the road pricing measure (tolling of proposed undersea tunnel) on the environmental indicators (air pollution and energy saving).
As regards long term capital projects, it is obvious that a new metro line influences the mode choice and that a new tunnel affect route choice. The table also shows that, in Thessaloniki, road tolling of undersea tunnel did not have significant impact on mode and destination choices and

that the measures related to parking management or to pedestrian and cycling are less relevant than expected (in the a priori table) for route and mode choices.
However the pricing measure tested was in fact road tolling of a new arterial and therefore it is not surprising that there has been no real effect in the traffic at the city centre. Different results must be
expected, should a cordon or a time based pricing is implemented.

The Thessaloniki model does not include the departure time and activity time choices and does not model explicitly tour patterns. We note the low impact that destination choice has on all the indicators except for accessibility. Mode choice has a lesser effect on all the indicators than expected, with a major exception on the accessibility indicator where the opposite situation occurs.

TDM Measures			***Evaluated indicators (group of indicators)***						
			Air pollution	Noise pollution	Energy saving	Functionality of the whole system	Financial	Accessibility	Equity
Main measures	Pricing measures	Road pricing	-		-	+	+	+	
	Regulation measures	Parking management	-		-	+	+	+	
		Traffic calming	+		-	-		-	
		Pedestrian and cycling	+		+	+		+	
Major infrastructures		Metro	+		+	+	+	+	
		Tunnel	-		-	+	+	+	

TDM Measures			***Investigated demand choices***						
			Assignment (route choices)	Departure time choices	Mode	Destination	Activity time	Trip frequency	Tour pattern
Main measures	Pricing measures	Road pricing	+		-	-		-	-/+
	Regulation measures	Parking management	-		+	+		+	-
		Traffic calming	+		+	+		-	-
		Pedestrian and cycling	-		-	-		-	-
Major infrastructure		Metro	-		+	-		-	-
		Tunnel	+		-	-		-	-

Tab. 71 - Thessaloniki

6.2.6 Geneva

The fuel pricing measure has a significant impact on all the considered indicators. Compared to the original table, Geneva reports lesser impacts for the regulation measures concerning pedestrians and cycling and larger impacts of staggered activity times.
As expected, doubling of fuel price significantly impacts route, departure time, activity time and trip frequency choices. We note the significant effects of the access control measure on travel choices and especially on departure time, activity time and trip frequency. The staggered activity time measure significantly affects all the modelled travel choices.

TDM Measures			Evaluated indicators (group of indicators)						
			Air pollution	Noise pollution	Energy saving	Functionality of the whole system	Financial	Accessibility	Equity
Main measures	Pricing measures	Road pricing (as fuel pr.)	+		+	+	+	+	+
	Regulation measures	Access control	+		+	+		+	+
		Traffic calming	+			-		-	-
		Pedestrian and cycling	+		+	+		+	
Complementary measures		Traffic lights	-		-	+		+	
		Staggered activity time	+		+	+		+	+

TDM Measures			Investigated demand choices						
			Assignment (route choices)	Departure time choices	Mode	Destination	Activity time	Trip frequency	Tour pattern
Main measures	Pricing measures	Road pricing (as fuel pr.)	+	+			+	+	
	Regulation measures	Access control	+	+			+	+	
		Traffic calming	+	+	+		-		
Complementary measures		Traffic lights	+	+					
		Staggered activity time	+	+	+		+	+	

Tab. 72 - Geneva

For Geneva, we note a higher effect of the departure time choice on some indicators, especially energy saving, financial aspects and accessibility. These last two are also highly dependent from the activity time choice. The noted effects of the trip frequency choice are based on the significant impacts noticed for the activity time choice.

6.2.7 Conclusions

In summary, we can note that the results from the test site evaluations generally agree with the original (a priori) table of the importance or relevance of different MOE indicators to show the impacts of alternative TDM policy measures, although some exceptions have been found[14].

The second set of tables (demand choices) shows a greater variability with respect to the a priori table than the previous set (indicators). This observation may be attributed to the varying degrees of service improvement, pricing or regulation at which the different TDM policy measures were analysed by different test sites. It has been also noted that the impacts of the TDM measures on travel demand choices were reported only for the choice dimensions that were modelled in each test site.

Furthermore, the test site analyses show in general that all the travel demand dimensions (route, mode, destination, departure time, …) have relevant impacts on the indicators selected for evaluation of TDM policy measures. This finding agrees with our expectations. A notable exception is the case of destination choice in Salerno where no significant effect on the indicators was measured. This is mainly due to the relevance in the Salerno test-site of trips made for systematic (constrained) purposes. It can be argued that more relevant changes could be noted if long-term effects are simulated, possibly also through land-use models.

[14] For example, in York it was found that the simulated bus-lane had little effect on PT travel time, against what was thought a priori.

6.3 Assessment of Demand Modelling Approaches

By critically reviewing the modelling approaches used in AIUTO we will draw general conclusions on the suitability and effectiveness of existing models. We first consider the existing approaches to demand modelling. The next section will be similarly devoted to assignment models.
Different types of modelling approaches to transport demand have been presented in chapter 4. As regards switching vs. holding approaches, the AIUTO experience has found that neither one of the approaches has shown an evident supremacy. In general, switching models (as the ones used in the Como test site) have been proved to have a generally easier analytical structure and to be less *data intensive*. In fact, only attributes related to changing vs. non-changing alternatives have to be estimated. On the other hand, at least in the particular approach used in **Como**, where switching has been applied only to car trips, the contribution of changes in other-modes is missed. In general, switching-type models should be further investigated both from a theoretical and a practical points of view.

The “all-day” and “peak-hour” approaches have been used within the AIUTO project. A non-negligible evidence has been shown that, for general cases, the all-day approach is recommended when TDM measures have to be assessed and evaluated. This is due to two factors. On one hand, most of the TDM measures could be intrinsically time-of-day-dependent; on the other hand, the effects of (even all-day-constant) TDM measures on the all-day-evaluated indicators cannot be *linearly* or *proportionally* derived from peak-hour (due to the strong non-linearity of the relationships among the variables). Finally, it should be noted that one of the non-negligible (and desired) effects of TDM measures is to *spread* some of the peak-demand, and therefore an activity time choice model is recommended.

Within the AIUTO project one of the test sites (**Randstad**) has explicitly considered the long term effects of TDM measures, while the other test sites have focused their attention on short-medium term effects. Even if the TDM measures were not intended for their long-term effects, it could be extremely useful to state the contribution of TDM’s to long-term changes in travel demand patterns. However, it seems that long-term prediction issues should be extended to transportation-land-use interaction models.

The AIUTO experiences have shown that a major modelling issue is related to demand model elasticity. Model elasticity should be regarded from two different aspects.

- Clearly, the modelled choices should be sensitive to the TDM measures. One cannot establish *a priori* which of the travel choices is influenced by TDM measures, so, in principle, all choice levels should be sensitive to TDM’s. The most *demand modelling oriented* of the test sites (**Como**, **Randstad** and **Salerno**) have faced the *elasticity challenge* by including in each choice model both attributes directly influenced by TDM measures and attributes which take into account the indirect influence that comes from other choice levels. Such an approach is consistent with the application of the nested LOGIT model.
- On the other hand, if all the demand models are sensitive to the policy measures, then an equilibrium problem arises. The modelling procedures should include an equilibration mechanism that allows (by an iterating approach) *smoothing* of the effects of TDM measures that, otherwise, will be unrealistic or, at least, overestimated.

The AIUTO experiences have shown that a suitable and effective way in which different travel choices can be integrated into a consistent theoretical structure is to use the nested LOGIT model (see the example in Fig. 11 on page 35). It allows the model to have an *open* structure in which non-standard choices (typically related to the expected impacts of TDM measures) can be consistently integrated. However, the data base needed to set up such a system of models should be sufficiently large and complex or of a particular type (e.g. choice based sampling) to cover all the possible alternatives for the included travel choices. A technique to overcome this problem can

be the use of the *limited information* calibration method that calibrates each choice model separately, instead of the *full information* method calibrating the whole system simultaneously. Although less precise, the limited information method strongly reduces the alternative set to be considered in the calibration process.
As can be observed from chapter 6, the number of choice dimensions that each of the AIUTO test sites have considered is quite different. One of the test sites has not used demand models at all (**York**), while all the others have implemented at least a *mode choice* model.

Some of the differences of the overall modelling structure among test sites are due to the fact that they simulate the application of different TDM measures. For instance, not all the test sites simulate parking policies, so not all implemented a parking choice model. However, some of the choice dimensions are indirectly affected from TDM measures other than the *direct* ones. For instance, a traffic restriction imposed in a given area could affect the parking pattern in a neighbouring zone; a proper system of demand models should take into account such an effect.

More generally, the interactions among (and within) the different components of the transportation system should be covered by the modelling system.

6.4 Assessment of Network Assignment Approaches

Assignment models play a crucial role where TDM measures are simulated. The outputs of assignment models are travel times and flows. The link flows and speeds are used to calculate some of the MOE’s that capture the impacts of the TDM policy measures. The travel times output are also the key input of the travel demand models. All the test sites used the assignment to predict link flows and all the test sites used the assignment model to calculate the travel times input of the travel demand models.

Loosely speaking, traffic simulation models can represent traffic flows at three levels. In order of decreasing “detail” these are: *microscopic, mesoscopic* and *macroscopic*. A microscopic model is one in which *individual vehicles are separately modelled*. In a typical microscopic model, vehicles have individual properties such as velocity and road position. For instance, the DRACULA model used in the **York** case study is a good example of an extremely detailed microscopic model. Different vehicles have different abilities to accelerate and different “styles” of driving behaviour (e.g., “cautious” drivers will not approach other drivers as closely). By contrast, in a macroscopic model, a flow of vehicles on a road is considered a continuous variable. For instance, the PFE model also used in the York case study, is an example of a macroscopic model. In PFE, vehicles are stored not as individuals but as flow-rates. The program then calculates the delays which would be experienced by a flow of that size on the road assuming a certain *cost-flow curve.* A mesoscopic model is one in which some aspects of behaviour are modelled macroscopically and some are modelled microscopically. For instance, vehicles can be grouped and the behaviours within a group are considered to be the same. In modelling urban networks it is considered that delays at junctions are more important than delays along links. Therefore some models use cost-flow curves along links and microscopic modelling at junctions.

Microsimulation is extremely computationally intensive when compared with macrosimulation. As available computer power increases, this will become less important but for the moment, this remains an issue worth considering when deciding which type of traffic simulation is most appropriate. Although it is impossible to say exactly what speed factor is involved, it is certainly considerable. Microsimulation models, however, have a number of advantages. Perhaps the most important of these is in air pollution modelling. However, general theoretical properties of microsimulation models are not so well established as in macrosimulation models.

The **York** test site compared the air pollution outputs of the SATURN model and the DRACULA model. SATURN is a macrosimulation model and DRACULA is a detailed microsimulation. The results obtained showed that the two models differ considerably in their predictions of pollutant levels. DRACULA predicted almost twice as much CO, one-fifth the amount of NO_x but similar values for fuel consumption and travel time. At least one contributory factor is the difference between macro- and microsimulation.
A vehicle which moves at a steady speed down a road has a greatly different emission profile to one which accelerates and decelerates a great deal during its journey. The DRACULA model explicitly calculates the way in which vehicles accelerate and decelerate while moving along a road, whereas the SATURN model attempts to infer this information from knowledge about the delays which the vehicle experienced. It is clear that, in the situations we looked at, these two approaches produced very different answers. It would seem that if we wish to get accurate models of pollutant emissions, the microsimulation approach must be used – although it may be possible that microsimulation models could be used to better calibrate the pollution modelling in a macrosimulation.

A number of traffic simulation issues are more readily modelled using a microsimulation type approach. For example, it is difficult for a macrosimulation to capture the idea of traffic signals being "in-phase" with each other. In a microsimulation model this is dealt with automatically since the vehicle will arrive at a signal during a red or a green phase and will stop or go accordingly. If two signals are phased to minimise vehicle delay along a route then this will be reflected in the travel time experienced in a micro-simulation.

Another main difference in assignment models is due to a static or dynamic approach. We can identify two areas where the "dynamic/static" issue is important. Some models simulate the different levels of congestion that are experienced at different times of day, as well as the time-dependent way in which flows propagate through the network. This type of model is referred to as "within day dynamic model". Other dynamic models try to represent the fact that the traffic patterns vary from day to day (e.g. because a new traffic scheme takes some time to reach its full effect and/or because the traffic pattern has implicit "inter-periodical" profile). Models of this type are referred to as "day-to-day dynamic models".

In within-day-dynamic models, the network performance, or supply model can be considered dynamic if the delays experienced by vehicles on the successive links of a route change according to the time at which they travel. This type of modelling can be achieved in a number of ways. Microscopic modelling, which was discussed above, is "naturally" dynamic since the vehicles are simulated individually, typically by using short time-slices (such as one second or even less).

Dynamic supply and assignment models capture several traffic characteristics which are not available in static models. A dynamic model is better able than a static model to capture "over-capacity" queuing because it follows the trajectories in time and space of the vehicles. This capability is accentuated by the fact that within-day-dynamic models also simulate the consequent spill-back problems.

Other issues related to within-day-dynamic models are:

- the demand matrix varies by departure time;
- vehicles can change their route choices according to the "dynamically" experienced travel time on the network.

One of the test applications within AIUTO considered the impact of a replacement of the static assignment model in an existing transport modelling system for the **Randstad** area by a dynamic version. Such an advance might be desirable for the simulation and assessment of many novel TDM measures, such as peak period pricing and information systems. A static equilibrium assignment model of the Randstad area and its surroundings for the 1994 base year network has been transformed into equivalent dynamic representations. Throughout this conversion the following objective has played a major role: to maintain the investment made in the static model, in terms of underlying data and level of validation with respect to observations. Three dynamic models were tested. The models have been compared with real-life observations and checked for internal consistency, while some sensitivity testing with respect to dynamic inputs also has been performed. The following conclusions can be drawn:

- the models achieve satisfactory convergence, but the dynamic models require 20-40 times longer run times that their static counterpart;
- overall network performance (in terms of average speed) is similar among the three packages, but significant and important differences do exist;
- the spread of congestion over road types differs substantially between the alternative models; as no reliable data exist, comparisons with real-life are not possible;
- the three models are capable of predicting the major congestion locations well, although there is little direct correspondence between individual links in each model and reality; it appears that the dynamic models show a greater similarity between themselves than with either observations or the static model;
- the dynamic models are reasonably capable of reflecting observed build-up of queues at main congestion sites; their proportional values are generally better than their absolute counterparts, although these discrepancies can be (at least partially) explained from the way in which queue observations are logged;
- the composition of affected traffic in queues shows a fair fit between models and observations.

In conclusion, a robust conversion of a static to a dynamic assignment model has proved possible, through a careful conversion of speed-flow-density curves, plus further fine-tuning of model-specific parameters. However, more work is needed on model refinements and validation.

Most of the supply and assignment models used within AIUTO are in various ways (and to varying degrees) based on the principle of network equilibrium. It is widely recognised that the equilibrium assumption provides a very useful and reliable basis on which to conduct transportation network analysis. However, the output of equilibrium models should be taken as estimates of an ideal situation which the real system is expected to tend towards. Bearing this in mind, it is perhaps worth having a closer look at the various types of equilibrium that were modelled by the assignment and supply models, since they lend themselves to slightly different interpretation of the same idea of equilibrium.

Equilibrium assignment models can be distinguished according to "*deterministic*" or "*probabilistic*" route choice model. They are respectively referred to as DUE (deterministic user equilibrium) and SUE (stochastic user equilibrium). Deterministic approaches represent the well-known *Wardrop principle*, while probabilistic models are generally based on PROBIT or LOGIT-type probabilistic choice models. Probabilistic assignment models are increasingly used in modelling practice, due to their more rigorous behavioural interpretation.

7. CONCLUSIONS

7.1 The Key Points of AIUTO

By reviewing the AIUTO Project with the aim of drafting some guidelines, we could highlight focus points or strong statements of the project itself. The points are, in our opinion, the following.

- *TDM's must be soft, reversible, flexible*

The transport demand management measures have such three characteristics: they are *soft* (i.e. without relevant infrastructure works), *reversible* (i.e. easy to reformulate at a later date to increase social acceptability) and *flexible* (i.e. responding as far as possible to different needs of users).

- *TDM's must be presented as packages*

The good results of these measures are often related to the implementation of a mixed set of them. In fact only one measure takes the risk to be ineffective (such as car pool) or unacceptable to car users (such as road pricing).

- *An in-depth analysis of models must be carried on*

AIUTO has carried on an analysis of the models suitable to simulate changes in the transport demand.

- *A simulation and evaluation path must be defined*

The phases of analysis, simulation and evaluation should be arranged in a logical path.
The analysis phase must take into account not only models suitable to simulate the alternatives, but also the important step in which packages of TDM are defined: it needs a sort of "scenario generator".
The simulation phase uses the modelling tools in order to obtain the results used as an input for the evaluation phase.
The evaluation phase has been thought as *a decision-making problem*, i.e. the problem of making a choice amongst different alternatives (at least two: to implement a TDM package or not): in this phase, different subjects are involved in the decision process with different sensibility to the selected criteria, so that *multicriteria analysis* should be the best tool to support the decision. A sensitivity analysis is however strongly recommended, as there is the possibility that the decision is influenced by little changes in data and/or weights.

TDM measures applied to the test sites of the AIUTO project have been assessed and evaluated by using different systems of models. Those systems represent an up-to-date sample of existing approaches to traffic and transportation modelling.

7.2 Recommendations for the Use of Existing Demand and Assignment Models to Evaluate TDM Measures in Different Urban Areas

Based on the results of the AIUTO projects, some general recommendations can be summarised. Of course, the general recommendations should be tailored for each test site, depending on the number and type of TDM measures that have to be simulated and/or on the size and type of the study area.

In the following Tab. ?? different demand and assignment models are listed. The demand dimensions are listed and, for each of these, different modelling approaches are taken into account. Where a choice can be made on which type of model could be used, both an "absolute" and a “relative” recommendation level is indicated. The absolute level refers to the need of including that dimension in the model structure, while the relative level refers to the use of a given type of modelling approach for a given dimension.

MODEL		CONCLUSIONS		
Choice level	*Model type*	*Modelling effort required*	*Level of recommendation*	
			Relative	*Absolute*
ROUTE CHOICE ASSIGNMENT	AoN (All or Nothing)	**+**	**N.A.**	**** (for TDM measures modelling)** ***** (for MOE’s) computation**
	DUE (Deterministic User Equilibrium)	**++**	****** §	
	SUE (Stochastic User Equilibrium)	**++**	****** §	
	MULTIUSER DUE	**+++**	**N.A.**	
	MULTIUSER SUE	**+++**	******	
	DYNAMIC (with Determ. Path choice)	**++++**	******	
	DYNAMIC (with Stoch. Path choice)	**++++**	*******	
MODE CHOICE	IMPLICIT ON NETWORK	**++**	**N.A.**	*******
	EXPLICIT (LOGIT TYPE)	**++**	*******	
GENERATION	TRIP FREQUENCY	**+**	*****	******
	ACTIVITY TIME CHOICE	**++**	******	
	TOUR PATTERN	**++++**	*******	
DISTRIBUTION	IMPLICIT ON NETWORK	**+**	**N.A.**	******
	LOGIT / GRAVITATIONAL	**++**	******	
	LAND USE (LONG TERM) IMPACTS	**++++**	*******	
PARKING MODEL	EXPLICIT CHOICE MODEL	**++**	***** (In case of parking measures)**	
ELASTIC DEMAND RE-EQUILIBRATION APPROACH		**++**	*******	

N.A. = Not Applicable
+ = low effort   * = not recommended
++ = medium effort   ** = recommended
+++ = high effort   *** = highly recommended
++++ = very high effort

§ **York** (the only site which compared SUE and DUE) drew no conclusions on the matter whether SUE should be generally more highly recommended than DUE. However SUE models are more general and seem to be related to more realistic behavioural hypotheses; they can perform better than DUE models in cases where networks are not largely and uniformly congested.

Tab. 73 - Recommended modelling approaches

7.3 Conclusions and Recommendations for Future Work

The previous sections of this report have synthesised the evaluations of the models and methodologies that were conducted by the six AIUTO test sites. The AIUTO test site evaluations were very useful both because of their heterogeneity and their commonality. The heterogeneity stemmed from the policies that were evaluated and the modelling capabilities that were used to analyse them. The commonality was in terms of the overall modelling framework, a classification of policies, the overall modelling structure and the measures of effectiveness.
Based on the experience from the test site applications, conclusions concerning the practical application of alternative modelling approaches can be drawn, and in particular dealing with the differences between deterministic user equilibrium (DUE) and stochastic user equilibrium (SUE), as well as between microsimulation and macrosimulation traffic models.
With regard to DUE vs. SUE models, criteria can be laid as to which is the more appropriate tool given certain circumstances. However, model-users are often convinced that only one approach is correct; i.e. they are committed adherents to either one of DUE or SUE. Given this, it is useful to make comparisons to examine whether the two types of model create essentially different output. As far as the AIUTO modelling is concerned, there was little difference (of importance) in results from DUE and SUE.
The bigger model differences concerned micro- vs. macro-simulation. The conclusions with respect to this are that traffic microsimulation models should be used for the following purposes:

– assessment of the effects of reactive traffic signal schemes,
– accurate estimates of pollution,
– accurate estimates of (good) safety indicators.

If, though, a traffic microsimulation model is to be used it must be properly calibrated with respect to delays of traffic on minor arms at give-way junctions. On the other hand, if assessment does not involve any of the above issues, it is sufficient to use either a macrosimulation (or mesosimulation) traffic model, such as Emme/2 or SATURN.

Some site-specific conclusions can be also highlighted. For example, from **Randstad** study some outcomes have been achieved, about the effect of *long-term planning* – some of its long term studies reverse the effects of the short term ones – thus, what is good “short term” may show reduced or even reversed effectiveness “long term”.
In **Como**, incentive (“pull”) measures, if applied alone, were found to be rather ineffective in terms of causing a modal change from private car, while a good performance was achieved by “push” measures (mainly involving road- or park-pricing).
The **York** case study highlighted highly divergent estimates of *pollutants* from two current models - one of which is widely used (SATURN). This points to an urgent need to further study possible inconsistencies in pollutant modelling, and makes one wondering if it is even possible to get accurate measures of pollutants using macro-simulation models. Actually, the extreme differences in pollution modelling outputs seem to indicate that the macro and micro-simulation approaches to pollution modelling are inconsistent. Since pollution modelling is extremely important, it is pressing to find out how this can be resolved, which is correct and whether the experience of the micro-modelling (assuming it is correct) can be used to better tune the macro modelling. Nonetheless, if accurate absolute (as opposed to relative) estimates of pollution are required by a strategic model, it seems highly desirable if the pollution sub-model of the strategic model is “calibrated” by a microsimulation model. Research needs to be conducted to examine the differences between different sets of pollution coefficients, and to make recommendations as to which set is appropriate to specific circumstances.

Furthermore, different *supply models* do not always agree on the same study: since good supply modelling underpins good demand modelling, it is urgent to investigate these modelling differences in order to provide a more sound basis for transport modelling in general.

Although the AIUTO project has demonstrated that adequate modelling capabilities to analyse TDM measures are generally available (in the form of disaggregated travel demand model systems and dynamic network assignment), from some site-results it appears evident that more validation tests would be useful for a better assessment of the accuracy of such models. As part of this validation process, it would also be useful to conduct comprehensive sensitivity analyses to identify the most critical aspects and the key parameters of the models.

However, the state of development of these tools is such that they are not yet readily available for wider dissemination or for quick policy analyses. In their existing state these capabilities require a long period of data collection and calibration. Moreover, their application requires heavy user intervention and too much manual data-handling from sub-model to sub-model, leading to increased time and error. Thus, their application to a new study area would call for a major investment in terms of time, money and involvement of highly skilled persons trained and experienced in transportation demand and network modelling.

Our key recommendation for further work is to conduct an AIUTO II project. The purpose of this follow-up project would be to develop a set of standard user-friendly software tools that would be used for quicker and easier applications of the models recommended by AIUTO. The new software would require less demanding skills from the end users and would also automate many of the functions that currently require user intervention. We propose to first develop the required software tools, and then, unlike AIUTO, apply a common set of tools with the recommended models to a range of test sites.

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9. ANNEX: THE DATA DICTIONARY

The AIUTO project involved different test sites belonging to different countries and with different problems to solve. For that reason all partners needed to use a common language to make easier the communication between the test sites users and to allow them to reference attributes, variables and any characteristic of transport demand and supply. In other words, the AIUTO test sites needed a common *Data Dictionary*.
The definition of the AIUTO Data Dictionary (referred to in the following as AIUTO-DD) *follows the principles of the methodology proposed by the consolidated* ALERT-STRADA *dictionary*[15].
Furthermore, since the AIUTO project deals with Urban Transport systems the idea was to follow some guidelines coming from the dictionary defined within the DRIVE II - QUARTET project (Quadrilateral Advanced Research on Telematics for Environment and Transport) which is related to Urban Transport Management area.
It is important to highlight that the AIUTO-DD constituted just a common language but it did not take into account the specific format of the data described and it did not provide strictly rules for using data in each test-site application.
Accordingly to the principles of the methodology proposed by the ALERT-STRADA dictionary, the AIUTO-DD classifies data according to these categories: the **data objects,** the **attributes**, the **data sets.**
The *data objects* constitute the words of the dictionary itself and they are described by a definition and a list of *attributes*. The objects can be also subdivided by a functional classification that will be presented at the end of this chapter into *data sets*; this final classification is related to the transport models which were treated in chapter 4.

9.1 The Data Objects

The AIUTO-DD is composed of a subset of the data objects proposed by the ALERT-STRADA dictionary with the addition of other objects which seem to be fundamental for describing the data base requirements of the AIUTO project.
The AIUTO-DD has been defined as composed of the following objects, with the correspondent code, where objects in *italic* are the new ones (specific for the AIUTO-DD).

Code	Data Object	Description
TRAFFIC DATA		
FLO	FLOW	Number of vehicles, axles, axle-pair or pcu (passenger car unit) which pass a fixed point in a specified time period.
PLD	*PUBLIC LOAD*	Number of passengers either being on board on public vehicles for each link and public line or getting on and off public vehicles for each bus-stop and public line.
CTT	CONCENTRATION (DENSITY)	Total number of vehicles present on a specified section of road at a particular time, divided by the length of the road.

[15] In DRIVE I, the project STRADA (Standardisation of TRAffic DAta Transmission and Management) produced a data dictionary for traffic operators, while RDS-ALERT was in charge of compiling a list of messages for information dissemination to drivers. In DRIVE II two main approaches appeared: the ALERT methodology based on the exchange of "situation data" assembled in messages, and the database query philosophy promoted by STRADA. Both orientations were integrated in a common structure by the DATEX task force and a consolidated ALERT-STRADA dictionary was made up.

Code	Data Object	Description
TTM	TRAVEL TIME[16]	Time taken to travel between specified points, including any time taken by involuntary stops and delays.
AVS	AVERAGE SPEED	Average speed, when a fixed distance is travelled (the harmonic mean of the speed of individual vehicles), i.e. the space-mean speed.
SRT	*SPLITTING RATE*	Value of splitting rate, at every link for all origins and all destinations.
DEM	*DEMAND*	Describes the trip frequency or Origin-Destination flows.
CAP	*CAPACITY*	Maximum value of flow which can pass a fixed point in time unit. It can be computed or forecast.
FRE	*FREQUENCY*	Frequency of the passage of the public transport means on a line of transport and in a specified period of time.
DIS	*TRAVEL DISTANCE*	Distance of a travel between specified points.
PKD	*PARKING DEMAND*	Describes the information related to the demand of parking.
TRAFFIC/TRAVEL CONDITIONS		
LOS	LEVEL OF SERVICE	Qualitative measure describing traffic condition and their perception.
PAR	CAR PARKS	Availability of spaces and of park and ride services.
MOB	*MOBILITY RATE*	Rate of mobility per class of vehicles.
CON	*CONGESTION*	Qualitative measure to indicate the level of congestion on a specific link in a particular time period (ratio between flow and capacity).
SEI	*SOCIO-ECONOMIC INFORMATION*	The object includes the socio-economic characteristic of a specific traffic zone or area.
CCS	*COMMUTER COSTS*	The object includes the social costs of the commuters.
ENVIRONMENTAL CONDITIONS		
WIN	WIND	Wind condition on the road.
EXH	POLLUTION	Air pollution.
ROAD CONDITIONS		
ACT	ACTIVITIES	Deliberate human actions external to the traffic stream or roadway which could disrupt traffic.
RWK	ROADWORKS	Includes all maintenance activities which may potentially affect traffic operations.
TRAFFIC REGULATIONS		
APL	ACTION PLANS	Pre-planned regulations or schemes which are prepared and implemented by the authorities or by a traffic operator. Action plans are triggered either on a periodic basis (e.g. yearly, weekly) or according to operational criteria.
OPA	OPERATOR ACTIONS	A traffic operator is an organisation responsible for the operation of a stretch or network of roads: this data object includes all actions that a traffic operator can decide or implement to prevent or correct dangerous or poor driving conditions.
RES	TRAFFIC RESTRICTION	Includes all restrictions on road usage, whether by legal order or by operational decisions. It includes road and lane closures, weight and dimensional limits, banned turns, counter-flows and alternate traffic operations.
SIG	TRAFFIC SIGNAL PLANS	Signal plan setting.
ART	ARRIVAL TIME	Arrival time of vehicles at a point (for example forecast arrival time of public vehicle at a controlled intersection).
PRI	*PRICING INFO*	Pricing information.

[16] The definition of TRAVEL TIME has been slightly modified to take into account the travel time between OD zones (the travel does not take place only by a specified route, it could take place also by more than one route).

Code	Data Object	Description
SURVEY DATA		
SUR	*SURVEY*	Describes the information collected by surveys.

Tab. 74 – The data objects

9.2 The Attributes

Each data object is described by a definition and a list of attributes which characterise it.
Following the guidelines proposed by DATEX, the objects can be described by the following **attribute sets**[17], more detailed in the ALERT-STRADA dictionary:

- identifiers;
- basic attributes (e.g. measurement unit, measurement period);
- time attributes (e.g. start/stop time, duration);
- location reference (e.g. node, link, zone, area, park);
- information features (e.g. forecast, source type, accuracy);
- other general attributes;
- attributes specific to one object.

The AIUTO-DD arises from the need of a common language to communicate between different test-sites users, but it does not aim to exchange information between processes. For that reason, the relative objects have been defined using a subset of the attributes proposed by DATEX.
The following table summarises for each data object, belonging to a specific object set, the list of attributes defined for the AIUTO-DD. The list of attributes was categorised into **attribute sets**, for a better explanation of the common characteristics of each attribute.
For each attribute set considered, a synthesis of the description used in the ALERT-STRADA dictionary and the list of attributes defined for the AIUTO-DD is reported. The attributes in *italic* are the additional ones which have been added to better describe the AIUTO data.

Attribute set: Identifiers (The set comprises attributes for the identification of situation data and information management in general: situation, version, sender, etc.).	
Attribute	**Description**
CODE	Abbreviated name of the entity (e.g. LOS for level of service).

Tab. 75 – Attributes of the Data objects. Attribute set: Identifiers

Attribute set: Basic Attributes (These attributes contain core information to which the other attributes add clarification or additions).	
Attribute	**Description**
UNIT	The unit of measurement used to qualify the object (if it has a dimension)
CLASSIFICATION	The attribute defines the classes into which other attributes are classified.
MEASUREMENT PERIOD	The length of time during which a measurement has been performed. The attribute may differ from the unit attribute (e.g. an hourly flow can be estimated from a 5-minute count).
MEASUREMENT LENGTH	The length of road on which a measurement has been performed. The attribute may differ from the unit attribute (e.g. concentration in veh*km can be measured over a 2 km section of road).

Tab. 76 – Attributes of the Data objects. Attribute set: Basic Attributes

[17] In other words the **attribute sets** are groups of attributes like the **object sets** are groups of data objects.

Attribute set: Time (This set of attributes deals with the time referencing of the objects).	
Attribute	**Description**
DURATION	Indicates the expected period over which the situation is thought likely to continue.
DELAY	Indicates additional travel time due to adverse travel conditions of any kind, when compared with "normal conditions".

Tab. 77 – Attributes of the Data objects. Attribute set: Time

Attribute set: Location Reference (The set deals with the geographic reference of the information which must tackle the different systems used).	
Attribute	**Description**
LOCATION REFERENCE	The geographic reference entity for the object. The location referencing system proposed for the AIUTO-DD comprises the following entity: node, link, turn, zone, line of public transport, parking area, path

Tab. 78 – Attributes of the Data objects. Attribute set: Location Reference

Attribute set: Information Features	
Attribute	**Description**
FORECAST	It is a binary attribute which may assume "yes" if the situation is a forecast, "no" if the situation is existent.
SOURCE TYPE	The attribute indicates the technology used for measuring the data or the method used for obtaining qualitative descriptions.
SOURCE NAME	The name of the organisation which has produced the information.
ACCURACY	Indicates the extent to which data may be subject to error.

Tab. 79 – Attributes of the Data objects. Attribute set: Information Features

Attribute set: Other General Attributes	
Attribute	**Description**
CAPACITY REDUCTION	It is the ratio of the current capacity to the normal road capacity, as a percentage. The capacity is the maximum number of vehicles which can pass a specified point on the road, in time unit.
VISIBILITY	It is the distance, measured or estimated, beyond which drivers may be unable to clearly see a vehicle or an obstacle.
DEPTH	The depth of rainfall, of snowfall, of flooding or of snow on the road.

Tab. 80 – Attributes of the Data objects. Attribute set: Other General Attributes

Attribute set: Attributes specific to one object		
Object	**Attributes**	**Description**
Parking demand	*TURN OVER*	Indicates the difference between the vehicles arriving in a parking area and the departing ones.
	SATURATION DEGREE	Indicates the level of saturation of the parking area.
	PARKING OCCUPATION	It is the number of vehicles in the parking area.
Level of service	NUM. LANES OF QUEUING TRAFFIC	Number of parallel lanes of queuing traffic.
	QUEUE LENGTH	The length of a queue or the average length of queues in separate lanes.
	NUMBER OF SERVICE LANES	The number of service lanes open to traffic at a toll plaza, custom point, etc.
	NUMBER OF WAITING VEHICLES	The number of vehicles waiting in a queue.

Attribute set: Attributes specific to one object		
Car parks	*PARKING DURATION*	Indicates the period over which the parking facility can be used.
	PARKING CAPACITY	It is the capacity of the parking facility.
Socio-economic information	*FLEET*	Indicates the fleet of cars referring to a traffic area.
	INHABITANTS	It is the number of inhabitants of a traffic area.
	ACTIVE POPULATION	Indicates the number of active inhabitants in a traffic area.
	EMPLOYED	Indicates the number of people who are working in a traffic area.
	NOT EMPLOYED	Indicates the number of people living in a traffic area who have not an employment or who are looking for a job (e.g. students, housewives, unemployed, etc.).
	STUDENTS	Indicates the number of students in a specific traffic area.
	ATTRACTIVE POINTS	Indicates the number of attractive points (like stadium, theatres, etc.) of a traffic area.
	SERVICES NUMBER	The number of services (hospitals, etc.) in a traffic area.
	AVERAGE INCOME	The average income of the inhabitants of a specific traffic area.
Commuter costs	*COST VALUE OF TIME*	Represents the social cost to drive one hour.
	COST VALUE OF EARLY ARRIVAL AT WORK	Represents the social cost to arrive early at work.
	COST VALUE OF LATE ARRIVAL AT WORK	Represents the social cost to arrive late at work.
	COMMUTER WORK STARTING HOUR	Indicates the hour when each driver tries to reach work.
Wind	AVERAGE WIND SPEED	The average wind speed measured at vehicle level.
	MAXIMUM WIND SPEED	The maximum wind speed in the measurement period.
	WIND DIRECTION	The average direction from which the wind blows.
Pollution	CARBON MONOXIDE CONCENTRATION	The concentration of CO in the air usually measured in parts per million.
	NO_X CONCENTRATION	The concentration of NOx in the air usually measured in parts per million.
Action plans	ACTION PLAN IDENTIFIER	Gives the code or identifier of an action plan.
Pricing info	*PRICING TYPE*	Indicates the type of pricing in terms of where the pricing is applied (parks, roads, etc.).
	TICKET TYPE	Indicates the type of the ticket used (e.g. daily ticket, season ticket, annual subscription, etc.).
Survey data	*SURVEY TYPE*	Indicates the type of the survey, Stated Preference or Revealed Preference.

Tab. 81 – Attributes of the Data objects. Attribute set: Attribute specific to one object

9.3 The Data Sets

An hypothetical architecture of a TDM package to be simulated by the transport models described in chapter 4 needs a database which can be organised in four groups of data, called **input data sets**:

- Socio-economic and demographic data
- Networks data

- Travel Demand data
- System Performance data

The *Socio-economic and demographic data* consist of all information which allows the traffic area to be described in terms of its demographic structure and which is useful for the demand modelling (e.g. inhabitants, families, activities, attractive places, schools, industries, etc.).

The *Networks data* include the information which describes the resources and the infrastructures related to a traffic network, therefore related to the supply system (both private and public). In particular the network data consist of:

- features of the network nodes for each modal network (both private and public)
- physical features of the links (for each modal network) which connect the nodes (e.g. length, width, lanes, etc.)
- functional features of the links (for each modal network) connecting the nodes (e.g. link type, parking features, capacity, free flow speed, etc.)
- features of the transit lines (type of the line, transit means, frequency, etc.)
- description of other infrastructures (e.g. parking spaces)

The *Travel Demand data* describe the overall mobility in the traffic area. In other words, the demand data include all the movements (of vehicles and passengers) in the traffic area and can be characterised by spatial, temporal and modal factors. The demand data can be obtained in several ways: e.g. using information collected by surveys and/or applying demand models.

Finally the *System Performance data* collect the information which refers to the users, to the operators and/or to the community. The performance data can be obtained both by surveys and by simulations. Data referring to the *users* take into account the performance of a traffic zone (or Origin/Destination zone), for example average travel time and travel distance, monetary cost, travel time on transit means, etc. Performance data which refer to the *system operators* are more related to links or networks (distinguished by mode) and for example they include link capacity, saturation degree, average link speed, frequency of transit means, etc. The third type of performance data concerns the community: for instance, they are related to environmental impact factors like energetic consumption and pollution.

The following table shows the interaction between **data objects** and the **data sets**.

Code	Data Objects	Data sets			
		Socio-economic information	**Network**	**Travel Demand**	**System Performance**
FLO	FLOW			x	
PLD	PUBLIC LOAD			x	
CTT	CONCENTRATION (DENSITY)				x
TTM	TRAVEL TIME		x		x
AVS	AVERAGE SPEED		x		x
SRT	SPLITTING RATE			x	
DEM	DEMAND			x	
CAP	CAPACITY		x		
FRE	FREQUENCY		x		x
DIS	TRAVEL DISTANCE				x
PKD	PARKING DEMAND			x	
LOS	LEVEL OF SERVICE				x
PAR	CAR PARKS		x		
MOB	MOBILITY RATE			x	
CON	CONGESTION				x
SEI	SOCIO-ECONOMIC INFORMATION	x			
CCS	COMMUTER COSTS				x
WIN	WIND				x
EXH	POLLUTION				x
APL	ACTION PLANS		x		
OPA	OPERATOR ACTIONS		x		
RES	TRAFFIC RESTRICTION		x		
SIG	TRAFFIC SIGNAL PLANS		x		
ART	ARRIVAL TIME				x
PRI	PRICING INFO		x		x
SUR	SURVEY			x	

Tab. 82 – The data objects and the input data sets relationship.

With reference to the hypothetical architecture, the models which compose a generic TDM package can require the following data objects (obviously the requirements may differ depending on the specific models applied):

TRANSPORT MODELS	**DATA SETS**			
	Socio-economic information	**Network**	**Travel Demand**	**System Performance**
Demand models	S.E. INFORMATION	CAR PARKS PRICING INFO	SURVEY DEMAND PARKING DEMAND MOBILITY RATE	TRAVEL TIME TRAVEL DISTANCE LEVEL OF SERVICE COMMUTER COSTS
Supply models		TRAVEL TIME AVERAGE SPEED CAPACITY FREQUENCY CAR PARKS PRICING INFO		
Assignment models		TRAVEL TIME AVERAGE SPEED CAPACITY FREQUENCY CAR PARKS ACTION PLANS OPERATOR ACTIONS TRAFFIC RESTRICTION TRAFFIC SIGNAL PLANS PRICING INFO	FLOW PUBLIC LOAD SPLITTING RATE DEMAND	CONCENTRATIO N TRAVEL TIME AVERAGE SPEED FREQUENCY TRAVEL DISTANCE LEVEL OF SERVICE CONGESTION ARRIVAL TIME

Tab. 83 – Data objects used by the transport models.