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**A NEW LOOK AT MULTI-MODAL MODELLING:  
MODELLING POSSIBILITIES REPORT**

**REPORT TO DETR, JANUARY 2001**

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# 1 INTRODUCTION

## 1.1 **Background**

1.1.1 In May 2000 the Department of the Environment, Transport and the Regions commissioned a consortium of consultants led by David Simmonds Consultancy, collaborating with MVA, John Bates Services, and the University of Leeds Institute for Transport Studies (ITS), to carry out a wide-ranging review of future needs for multi-modal modelling and of how these needs may be met. The Brief specified three parts to the study:

- an assessment of future modelling requirements
- a review of current and emerging possibilities, and
- an assessment of possibilities against requirements, leading to recommendation

1.1.2 This Report addresses the second of these issues.

## 1.2 **Scope and approach**

1.2.1 The Modelling Possibilities Review needs to consider

- the development of modelling techniques (from theory to workable techniques – not the commercial supply of software)
- the supply of data
- the possibilities for computation
- the availability of personnel able to develop and use models.

1.2.2 We have sought to ensure that for each stream of modelling work, the non-specialist (that is, non-modeller) reader can through careful reading understand

- the objectives of that work
- what kind of decision-making it might inform (if that is not explicit in the objectives)
- the fundamental characteristics of the approach
- what is novel about it, and in what respects it builds on previous experience
- its dependence on new or large-scale data sources/computing
- the editors' assessment of the degree of promise it shows.

- 1.2.3 We have not aimed to achieve an overall “agreed view” – on the contrary, differences of view about the future development of modelling, or about the viability of methods currently being developed or considered, will be made explicit. Further, whilst we include references to published material wherever possible, the need to look at emerging techniques and current work means that the Modelling Possibilities Review should not be considered as a “Literature Review”.
- 1.2.4 The work on the potential future of modelling began with assessments of the state-of-the-art which the consortium commissioned from a number of leading practitioners. The intention was emphatically not to seek a review, but to ask authors to address the challenge of proposing how their defined area might develop over the next decade, the particular contribution which it could make to general practice within the transport planning process, and the obstacles (both modelling and institutional) which will need to be overcome in order for its potential to be realised. Authors were asked to consider whether the particular modelling approach can satisfy the test not only of a sound theoretical conceptualisation, but also that of present – or foreseeable – practicality, in terms of both the data to support it and its computability.
- 1.2.5 These commissioned contributions have been supplemented by a general invitation to transport researchers to identify ideas and projects from which future modelling methods may emerge.

### **1.3 Structure of the Report**

- 1.3.1 Chapter 2 discusses the way in which we classified differing modelling approaches, and consequently how we selected the areas for which the assessments were commissioned.
- 1.3.2 Chapter 3 reviews the general findings from the commissioned work, as well as our attempts to canvass more widely among the Transport Research community. The assessments themselves, along with selected details of the Research community responses, are attached as Appendices.
- 1.3.3 In Chapter 4 we present our preliminary conclusions on the way forward.
- 1.3.4 For readers who may be less familiar with transport modelling, we have provided boxes containing definitions of some of the key concepts relating to models used in current practice. The ideas underlying new or less common models are introduced in the text. The Index should help, if necessary, to locate these. For practical reasons the Index relates only to the main text of the Report, not to the Appendices.

### **1.4 Acknowledgements**

- 1.4.1 We would like to acknowledge the contributions made by the authors of the four commissioned Appendices; by all those who responded to our request for information about model developments (listed in Appendix F); and by Steve Grayson, Project Officer, and his colleagues at DETR through their comments on earlier drafts.



## 2 CLASSIFICATION

### 2.1 Preliminaries

- 2.1.1 In order to make progress, we had to adopt some classification of alternative methodologies, and this in itself is not straightforward. Methodologies are sometimes differentiated on the basis of particular kinds of data, or particular forms of data analysis, even though general principles may be very similar. Researchers may also have an interest in either identifying with an existing methodology or in setting up an apparently new approach.
- 2.1.2 In addition to our pre-existing knowledge of modelling approaches and developments, we examined of the modelling papers presented at the 1998 World Conference on Transport Research in Antwerp, and at the 2000 International Association for Travel Behaviour Research conference in Queensland, Australia, and at recent European Transport Conferences.
- 2.1.3 There are two dimensions which can usefully be distinguished. The first is **the conceptual approach**, or what it is that a modeller is trying to do: this is what really differentiates one methodology from another. The other dimension is **the range of techniques** which are used within the methodology. Typically, the techniques which may be applied have wider relevance, both within transport studies and in other fields. We can therefore envisage imagine a cross-classificatory matrix of methodologies, in which the techniques are ways of implementing the conceptual approach.
- 2.1.4 The “classic” approach to transport modelling is that of the “four stage model”. We see this as part of a wider “mainstream” methodology, central to transport modelling since its emergence in the late 1950s, which includes many variations both of approach and technique. Our approach here is first to discuss this “mainstream” methodology, and then to identify and contrast alternative approaches, noting the “leading-edge” work in each area.
- 2.1.5 Our discussion has concentrated on the forecasting of **travel**. The “classic” four stage model starts from a given “land-use” description, which relates not only to the location of population and workplaces, but also the key topic of **car ownership**. This has been investigated extensively in its own right, using a wide

*The four stages of the four-stage model are*

- *generation – forecasting how many trips are made*
- *distribution – where the trips will go*
- *mode choice – how they get there*
- *assignment – which route they take (especially in the highway network)*

*The sequence of distribution and mode choice may be reversed, and there may be iteration between stages (see Table 2)*

**Table 1 The four-stage model**



range of approaches. For reasons of time limitation, we have treated work in this area somewhat cursorily, though it is addressed within many of the alternative methodologies. Our emphasis on the modelling of travel, as opposed to car ownership, reflects our belief that this is the more challenging area – it is not in any way implied that the modelling of car ownership is any less important, nor that there is not appreciable scope for “new” methodologies in this area as well, in the light of emerging issues.

## 2.2 **Mainstream approaches**

2.2.1 The characteristics of the mainstream methodology imply a model with:

- a **zonal** basis, thus implying some level of spatial aggregation;
- demand measured by **trips** or **tours**, more or less segmented;
- a **static** or **cross-sectional** structure (all demand and supply variables related to the same point in time);
- a structured set of **travel choices** usually corresponding to those of the four-stage model (see Table 1), but not necessarily applied that way, eg they may be structured into a variety of simultaneous hierarchical models; and
- a requirement in principle to iterate to **equilibrium**, more or less completely achieved in practice.

2.2.2 Although, as noted, the zonal basis requires a level of aggregation, this does not rule out the possibility of the **estimation** of the models being on an entirely disaggregate basis, nor of the forecast matrices being produced by essentially “micro” techniques such as sample enumeration.

*In many transport models, **iteration** is needed (though not always carried out) to achieve **equilibrium** in the results. This is because the outputs from one stage of the model are inputs to an earlier stage – the most common example being that car drive times are output from the assignment but input to mode split. If the model is not iterated to equilibrium, the different stages will be inconsistent.*

### **Table 2 Iteration and equilibrium**

2.2.3 With this kind of definition, much of what are often independently classified as “disaggregate” or “discrete choice” models can be viewed as an enhancement of the four stage model, rather than as a departure from it, and to that extent, part of the “mainstream”.

**Trips** are generally defined as a single journey from one place – the origin - to another – the destination.

**Tours** are generally defined as a sequence of trips from one origin to one or more destinations and back to the origin

### **Table 3 Trips and tours**

2.2.4 The more developed four stage models accept the need to distinguish between different times of the day (eg peak vs off-peak), and although the modelling problems remain significant, the addition of a “fifth stage” to allow for **choice** of time period does not seem to be a difference in the essential concept. We have therefore included time of day choice in the mainstream classification.

2.2.5 The borderline might be considered to be the treatment of “trip linking”. The original four stage models were firmly rooted in the assumption of independence between different trips made by the same traveller. More developed versions allow some interdependence between outward and return journeys for the same purpose. This is very close to the “primary destination” tour approach of the earlier “disaggregate” models.

*Aggregate models represent classes of travellers, described by their average characteristics; the classes may be more or less segments, eg to distinguish groups with different income levels.*

*Disaggregate models represent individual travellers, which can be described by their individual characteristics. The initial model results are the probability that each individual will choose each available alternative (cf microsimulation) . Typically a sample of individuals is used, and results for the sample must be factored up to obtain total results for the system.*

**Table 4 Aggregate and disaggregate models**

2.2.6 However, the emergence of more explicit trip linking methodologies, dealing more effectively with non-home-based movements, as well as the allowance for interactions between persons within the same household, does seem to be a significant departure from the four stage approach, and moves towards some of the characteristics of **activity-based models** (see section 2.3 below).

2.2.7 It therefore seemed that developments such as the Stockholm model described by Algers *et al* should be examined in more detail, pending the question of whether they need to be classified as an alternative methodology.

On this basis, we commissioned Staffan Algers, of Transek, Sweden, to reflect on progress at the fringes of Mainstream methodology where substantial advance is still taking place. His paper is attached as Appendix A.

2.2.8 Ultimately, any modelling approach needs to satisfy not merely the test of a sound theoretical conceptualisation, but also of present or foreseeable practicality, both in terms of the data to support it, and its computability. We identified three alternative approaches where we judged that substantial progress has already been achieved:

- activity modelling;
- dynamic modelling; and
- some forms of land-use/transport modelling.
- These approaches are briefly discussed in the following three Sections. At the end of the Chapter we consider some other approaches that have been proposed, and also provide some discussion of **techniques**.

**2.3 Alternatives to the mainstream: activity modelling**

2.3.1 The first major category which we have recognised as distinct from the “mainstream” approaches is that based on activities rather than travel demand *per se*. This is an alternative modelling stream of considerably long standing: however,

it is only very recently that it has been viewed as a **potentially** mainstream approach. At least partly, this has had to do with data requirements, which are generally far more demanding, but it has also been due to a failure, or possibly lack of interest, in following through the network **supply** implications of the predicted travel demand.

- 2.3.2 The hallmark of activity analysis is the fundamental assumption that the use of time in classifiable activities, potentially in different places, is the underlying motivation for travel. While it would be unfair to say that this is not recognised by (many) travel demand modellers, the activity analysis approach does involve a very different perspective. indeed, viewed within the context of activities, where the nature and **duration** of the activity is the major interest, travel between activities is only a minor detail.
- 2.3.3 There now appear to be model structures which start from an activity perspective but do mesh much more directly with the traditional description of transport networks – in this respect, the Portland, Oregon work seems to be the most highly developed. An important ingredient here is the microsimulation component, which was briefly discussed above.
- 2.3.4 Because of the interest in time allocation to activities, models of **duration** are often required. This is an area of some interest in its own right, and its transport interests extend beyond activity analysis<sup>1</sup> (for example, into car replacement decisions). This remains a highly specialised topic. Our current view is that it represents more of a technique than a conceptual approach in its own right, though one which may become increasingly important in dynamic modelling (see below).
- 2.3.5 Given the above considerations, we asked Kay Axhausen, Professor at the Institut für Verkehrsplanung und Transporttechnik (IVT) of the Swiss Federal Institute of Technology at Zürich, to make a contribution to the study. His paper is attached as Appendix B.

## 2.4 Alternatives to the mainstream: dynamic modelling

- 2.4.1 The next major category which we recognise as distinct is that which takes a dynamic viewpoint of the evolution of travel demand rather than taking a cross-sectional static equilibrium perspective. Once again, this is an alternative modelling stream of considerably long standing. Here, however, a large number of technical and terminological issues have led to a considerably less cohesive corpus of work than that for activity analysis.
- 2.4.2 The term “dynamic” is wide and consequently somewhat ill-defined. In principle, it can be applied to any inter-temporal dependence where the outcome at any point in time depends on the consequences of earlier outcomes or decisions. For example, there is a whole class of traffic assignment problems collectively described as

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<sup>1</sup> Note that “duration” may refer to anything from the length of time spent by an individual on one activity in one continuous period at one place (probably hours, maybe only minutes) to the length of time that a household resides in the same house (probably years and possibly decades).

“dynamic assignment” related to the build-up and dispersal of queues on the network. Although this is clearly a dynamic problem, it is much more narrowly focussed than is the intention of the classification “dynamic” in the current context: indeed, it can be argued that dynamic assignment has a role to play within the static four-stage model.

- 2.4.3 A further kind of dynamic analysis is the “within-day” temporal dependencies of the standard activity analysis framework, allowing for the fact that (at its simplest) return journeys can only take place after the outward journey etc. Again, while there is an obvious need for this, it falls outside the proposed classification on conceptual grounds.
- 2.4.4 Yet another aspect which is often classed as dynamic, because of its emphasis on the detailed treatment of time, though it is not strictly a dynamic effect, is the role of **variability**. The cross-sectional modelling of the four-stage approach typically makes use of an “average” state (very often, quite ill-defined!), whereas in reality it is known that both demand and traffic conditions are highly variable. There is also some suggestion that the “gross” variability in demand is substantially greater than the net variability.
- 2.4.5 However, the main aspect of dynamic modelling in which we are interested involves the concept of learning or adaptive processes. At one level, it may be sufficient to allow for a “history” on the part of the “stimulus” (cost) variables, as opposed to assuming instantaneous responses. More ambitiously, there may be an attempt to understand the adaptive process.
- 2.4.6 Clearly, the analysis of these processes is facilitated by a) longitudinal data, and b) explicit recognition of changes over time in modelling, including approaches such as duration modelling (see 2.3.4 above). As usual, therefore, there are data and estimation implications from pursuing a particular modelling methodology, though our approach is to regard these as variations of technique rather than concept.
- 2.4.7 Given the above considerations, Dr Henk Meurs, Principal of the Netherlands consultancy MuConsult, was invited to make a contribution to the study. His paper is attached as Appendix C.

## **2.5 Alternatives to the mainstream: land-use/transport modelling**

- 2.5.1 We are concerned here only with those aspects of land-use/transport modelling which offer alternative approaches to modelling transport demand. Since the modelling of land-use change itself is outside the scope of this study, we confine ourselves to those components of certain land-use models which either
- generate transport demands, or
  - represent other transport-related effects such as car-ownership,
- in ways which are different from the approaches listed above.
- 2.5.2 We concentrate here on the generation of transport demands; we need to consider further how much attention this study should give to issues such as car-ownership.

- 2.5.3 In considering how land-use models influence transport demand, it is useful to refer to the IL/LI distinction which was elaborated in the recent DETR *Guidance on Methodology for Multi-Modal Studies* (Volume 2, page B9). This refers to the models' approaches to the linkage between
- the location of activities and
  - the interactions between those activities.
- 2.5.4 One approach, which may be called the “**interaction-location**” or **IL** approach, treats the interactions as the main determinants of location, and finds the quantity of activities located in each zone from the interaction totals. For example, the number of workers living in a zone is found by first predicting the whole pattern of commuting, then summing the number of workers commuting from that zone of residence to all possible workplaces (including intra-zonal commuters).
- 2.5.5 The alternative “**location-interaction**” or **LI** approach treats the location (and number) of activities as the main “driver” of change, and then models the interactions between those located activities.
- 2.5.6 IL models predict matrices of interactions which can be converted into matrices of the demand for transport. These matrices would in the ideal model generate all of the derived demands for transport, though in practice some demands are usually left as exogenous. A sub-model must be included to convert the interaction matrices, which are typically measured in monetary units or in terms of persons or households, into travel demand units.
- 2.5.7 LI models may or may not generate such matrices, or they may generate matrices for some travel purposes but not others. The original application of the DELTA land-use modelling package in Edinburgh, for example, did not represent any interaction matrices; the land-use model simply provided estimates of zonal population, households, employment etc from which the START transport package estimated the generation and distribution of travel. That application is therefore irrelevant to the present discussion, but subsequent applications of DELTA (eg in Greater Manchester) have modelled matrices of commuting, and therefore are relevant.
- 2.5.8 The present study will therefore need to review the present status and future potential of IL models in general (as applied to generating passenger travel demands) and those aspects of LI models which generate travel.
- 2.5.9 Given the above considerations, we asked J Douglas Hunt, Professor of Transportation Engineering and Planning at the Department of Civil Engineering in the University of Calgary in Canada to make a contribution to the study. His paper is attached as Appendix D.

## **2.6 Alternatives to the mainstream: discussion**

- 2.6.1 While the three identified approaches seem to us the most developed alternatives, many other possibilities have been proposed. In 1990, the Department set up a seminar on “Longer Term Issues”, with aims some of which were similar to the

current project: the proceedings were published as Rickard (1991). A contribution by Goodwin (§3. *op cit*) reviewed the wide range of modelling approaches, and in a section entitled “Reclaiming the ‘marginal’ research of the 1970s and 1980s”, noted a number of promising approaches which were “outside the mainstream”. In addition to areas associated with dynamics and activity analysis, he refers to (*inter alia*) Time Budget studies, microsimulation using Monte Carlo methods, Markov chains, systems dynamics.

- 2.6.2 In reflecting on these, and other areas which emerge with some prominence in the recent conferences, we need to assess carefully to what extent they reflect conceptual differences as opposed to difference of technique. We will have more to say on this important issue below.
- 2.6.3 Alternative, more “rule-based”, perspectives have been put forward, particularly in the context of “fuzzy set” theory, genetic algorithms and “neural networks”. Other “non-compensatory” models such as those based on game theory and “Elimination by aspects” have been promoted in the past, though currently these seem to be attracting less interest. It is not clear how far any of these differ from the more standard econometric approach **in practice**, even if their conceptual foundations appear to be different.
- 2.6.4 Two other areas of work which should probably be classified as “techniques” rather than “approaches” are the related fields of cellular automata modelling and agent-based modelling. A cellular automata model “can be described as a two-dimensional array of regular spaces (cells) which are, at any given time, in a state that is determined by the attributes of neighbouring cells according to some uniform transition rules. Adjacent cells alter their states through the recursive application of these rules.” (Torrens, 2000, p60).
- 2.6.5 Agent-based approaches have something in common with cellular automata but take the agent (eg a person or a household) as the basic unit, representing how agents act in interaction with each other and with their environment. A critical feature is that all agents in the population of interest must be modelled individually – unlike disaggregate and microsimulation methods in which it is generally possible to represent a sample of the population and to factor up the results. A related characteristic is that the behaviour of groups should emerge as a result of the behaviour of the component individuals – the best known illustration being in modelling the movements of flocks of birds.
- 2.6.6 In transport-related fields, agent-based modelling has been used to represent traffic dynamics and pedestrian flows (see for example Batty, 1999). Its relevance will need to be considered further, though at present it would appear (a) that applications are most likely to be for physically small systems (such as a building or an intersection), and (b) if it becomes more widely applicable, it most likely to constitute a particular technique for applying short-term dynamic models. Cellular automata modelling seems less obviously relevant to the present study, but should also be kept in mind.
- 2.6.7 The Systems Dynamics approach (also referred to by Goodwin, above) has aroused periodic interest ever since the pioneering urban work by Forrester (1969). As its

name indicates, it has the property of describing the evolution of systems through time. However, the nature of the approach tends to put the focus on representation of the performance of the system as whole, rather than on understanding the decisions of the actors whose behaviour determines that performance; as such it is at odds with the majority of research and modelling which seeks to focus on actors' behaviour.<sup>2</sup>

- 2.6.8 For related reasons, a major drawback to the use of Systems Dynamics in transport is its restricted dimensionality other than in the temporal field. Hence, while this is certainly an alternative methodology, rather than a technique, its use is effectively confined to one-dimensional "system-wide" topics (such as, possibly, car ownership) rather than the detailed spatial requirements of travel modelling. Meanwhile, many of the desirable characteristics of Systems Dynamics, notably the impact of resource restrictions and complex feedbacks over time through multiple linkages, are being achieved in other, more behaviourally-based models.
- 2.6.9 Similarly, the recent SACTRA Report "Transport and the Economy" (SACTRA, 1999) has recommended more research into "Computable General Equilibrium" (CGE) models for understanding the "total economic impacts of transport schemes". CGE models recognise the existence of imperfect competition, and non-constant returns to scale. To **some** extent they can be seen as an alternative to Land-Use Transport Interaction (LUTI) models. We may cite the SACTRA Report directly: (para 4.71):
- "The evidence presented...both by LUTI model proprietors and independent commentators agrees that there are key features of the CGE approach that do not appear in current LUTI models. These include imperfect competition, location decisions of firms, economies of scale and agglomeration effects. .... We have received conflicting advice on the feasibility of extending LUTI models to incorporate these missing features and are not convinced that this can readily be accomplished."
- 2.6.10 It should be noted, nonetheless, that CGE, at least in its current applications, is a highly "macro" level system-wide approach, operating at the level of individual countries or, at best, regions. Whatever its value in improving the understanding of transport impact on the economy, it is unlikely to be a practical tool for forecasting the spatially detailed effects of particular policies. The LUTI models do have this potential, even if they do not describe all the relevant aspects of the economic system.
- 2.6.11 Approaches based on travel time budgets, again referred to by Goodwin above, have had a chequered history: the difficulty has been in making a convincing behavioural link between the observations (not always clearly defined!) relating to apparent consistency, at the aggregate level, in the amount of time spent travelling in widely disparate communities, and the implicit constraints on travel choice. We

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<sup>2</sup> Hence the jaundiced definition in the *New Fontana Dictionary of Modern Thought* (1999): "Systems dynamics is ... a style of model-building in which large structures are built which make little use of empirical evidence or previous knowledge of the subject".

remain unconvinced by most of the applications which have developed in this area, which has not received much attention of late. It would appear that time budgets may be potentially valuable as constraints on models (and must be important in activity models which seek to account for all time, not just for travel time), but that they are insufficient as a basis for models in their own right. We take a similarly cautious view of recent work by Kölbl and Macdonald (brought to our attention following our search for new approaches), which has attempted to broaden the concept to the notion of an Energy Expenditure Budget, based upon the physical energy expended by the traveller.

- 2.6.12 As noted, many of the areas which emerge in the recent conferences seem to us more in the realm of techniques. To take an example, the basic assumptions of the four stage model are entirely reconcilable with discrete choice theory, even if they were not originally conceived that way! Thus there is a unity of modelling perspective based on the notion of random utility, almost invariably using forms of logit modelling, because of its analytical tractability.
- 2.6.13 The generic use of microsimulation (also referred to by Goodwin, above) has made significant advances of late – mainly, it may be supposed, because of enhanced computing power. Although this is sometimes put forward as a modelling approach in its own right, it is more productive, in our view, to see it as a means to an end, and thus a **technique**. Nonetheless, it has considerable flexibility, which gives it great appeal. In the first place, it is well adapted to the “rule-based” concepts just referred to, while it can also be used as a device to make headway with analytically intractable calculations (such as multiple integrals). It also has the apparent ability to mimic “real life” behaviour, which makes it an appealing research tool.

*Like disaggregate modelling, **microsimulation**, involves considering the characteristics and choices of each individual in a sample, and calculating the probability of each individual choosing each travel alternative. However, instead of working directly with the probabilities, they are used in randomly allocating the individual to one particular alternative. Again as with disaggregate modelling, the sample results need to be factored up to obtain overall results. Repeated runs of a microsimulation model will generally produce slightly different results due to the operation of the random element.*

2.6.14 Despite our view that microsimulation constitutes a technique, not an approach in its own right, it is becoming such a favoured tool that further discussion is appropriate. We therefore return to it in section 3.4, after reviewing the various approaches identified above.

**Table 5 Microsimulation**



### 3 THE MODELLING POSSIBILITIES

#### 3.1 Introduction

- 3.1.1 The contributions from the four invited authors, after a small amount of approved editorial amendments, are attached as Appendices to this Report. In this Chapter, we draw some overall conclusions. For reasons which will become apparent on reading the Chapter, we deal with Dynamic Models first, and then with the other three categories as a group.
- 3.1.2 In section 3.4 we discuss, in rather more detail, the key “technique” of microsimulation. We also comment (in section 3.5) on the material we have found about other possible future modelling methods following our general invitation to transport researchers to identify appropriate ideas and projects.

#### 3.2 Dynamic Models

- 3.2.1 The paper on Dynamic Modelling by Meurs concentrates almost entirely on the question of panel data, which in his view is the dominant issue and obstacle to the application of such methods. The techniques for the analysis of longitudinal data are now reasonably well established, even if their details are not particularly widely disseminated.
- 3.2.2 Much of the discussion in this area relates to the inherent practical problems with maintaining panels. While Meurs is in general optimistic, it is undoubtedly the case that these have been a barrier to bringing the principles of longitudinal analysis further into the modelling mainstream.
- 3.2.3 A key document summarising progress, referred to by Meurs, is the 1997 volume edited by Golob, Kitamura & Long, containing specially commissioned papers from most, if not all, the experts in the field for a conference on “Panels for Transportation Planning, Methods and Applications”. The volume has recently been usefully reviewed (Tischer, 2000), and it is worth quoting from a salient paragraph in her review:
- “The last section of the book deals with efforts to develop dynamic models. Since few panel data sets existed until recently, little energy had been spent in developing or applying dynamic models. Mark Bradley notes that most panel data are used to monitor changes and not to predict them: therefore, the analytical techniques are not as well developed and even less used in practice.”
- 3.2.4 The relative lack of development in this area is confirmed by Meurs:

“With respect to the forecasting quality for transport issues no evidence is available. Forecasting using panel data models is in its start-up phase. However, the superior quality of parameter estimates with respect to biases as outlined in previous sections and the ability to capture adjustment processes, imply that expectations may be set high.”

- 3.2.5 With this in mind, it was thought sensible to give more consideration to the two papers in the cited volume which appear to have taken the process furthest. They are strikingly different in approach and content.
- 3.2.6 The paper by Bradley is a highly persuasive example of how longitudinal data can enrich the range of possible models. Keeping the approach as simple as possible, he develops four “dynamic” models for comparison with two “static” models estimated on the same data. The dynamic models test: a) straightforward lags in the independent variables, b) the choice made in the previous period as an explanatory variable (“inertia”), c) model conditioned on previous choice, and d) changes in choice explained by changes in independent variables.
- 3.2.7 Although there are differences in both the fit and the impact of the main independent variables, they are not especially marked. Nonetheless, the implications of accepting the dynamic elements in the different formulations and then simulating progress through time are markedly different. Further, although there is some **tendency** for elasticities from the dynamic models to be larger (in absolute size) than those from the static models (in line with generally received wisdom), this is not true of all the formulations.
- 3.2.8 Although he is at pains to point out that the models are very simple and only intended for discussion, an important conclusion drawn by Bradley is that:
- “More attention needs to be given to the dynamic behavior of models. The model specification and assumptions used in prediction can predetermine that a certain type of dynamic behavior will be generated, which may or may not have much to do with actual human behaviour.”*
- 3.2.9 The paper by Goulias and Kitamura, in stark contrast, describes a highly ambitious demand forecasting model based on “dynamic microsimulation”. Given the scope of the paper, few details can be provided, though the individual components are referenced in other publications. The authors claim of their model system that it
- “can replicate reality with accuracy comparable to other forecasting models. It represents a credible approach to forecasting travel demand and analyzing the potential impacts of transportation management improvements. However, the method is complex, poses high demands in model estimation, requires a large amount of data from panel surveys (which are not commonly available), and necessitates a “geographic” component to forecast traffic patterns on the highway network”
- 3.2.10 It is noteworthy that this last item (ie the network supply model) is not in fact present in their system. This is an acknowledged weakness, and features prominently in their recommendations for further development.

- 3.2.11 While we should certainly take Bradley's warnings to heart, the individual component models described by Goulias and Kitamura would appear to have been carefully estimated on a well-conceived data set. Our concentration here is on the details of the forecasting system (MIDAS). There is a "Socio-economic and Demographic Component" which deals with individual's progress through time in respect of birth, death, marriage, household formation and dissolution, licence-holding etc. This is a massive undertaking with a number of sub-components.
- 3.2.12 Then there is a "Mobility Component" which allows for Car Ownership and **Pre-distribution** modal split (necessitated by the lack of level-of-service data).
- 3.2.13 Some effort is made to address the statistical problems of micro-simulation by repeating the process with different random number seeds. Generally, the attention to detail and the data handling are impressive. However, without a supply function to represent, *inter alia*, congestion impacts, they have not been obliged to confront the more general question of equilibrium. Moreover, given that the emphasis of the model is dynamic, it is somewhat depressing that all the comparisons against other candidate models in the same context that they present are in terms of **absolute** levels. All the models compared are, in fact, "incremental", in that they start from an "observed" base position.
- 3.2.14 In addition, we do not learn how much of the detail is in fact relevant to the forecast outcome. The model, in other words, is a demonstration of **feasibility** rather than desirable *per se*. It would be a major piece of research to clarify the contributions of different components, and to assess their value against the increased complexity. Moreover, despite the scale of the approach, it is not clear whether a) in **concept** this represents any more than a micro-level application of the ideas common in land-use modelling, or b) there is in fact any intrinsic development over earlier work already carried out by Professor Wegener and colleagues at the University of Dortmund (see for example, Wegener, 1985).
- 3.2.15 Although this remains an extremely interesting area, and progress may be quite fast, it is clear that there is much fundamental work to be done before the massive complexity of the approach could be judged to have practical modelling value. It seems likely that in the short to medium term, there are simpler, more approximate, ways of introducing the insights obtained from the analysis of longitudinal analysis to practical forecasting models.
- 3.2.16 An approach which would seem to fall under the general heading of dynamic models, though not discussed by Meurs, is that of duration modelling. There is a considerable literature in this area (for a useful review, see Hensher & Mannering, 1994), particularly in relation to car ownership (for example de Jong, 1996).

### 3.3 Mainstream, Activity Analysis, and Land-Use Models

- 3.3.1 In the case of the contributions we have received on the other three areas, there is an interesting convergence of views (given that no liaison appears to have taken

place). The position is usefully summarised in the diagram by Hunt, whose structure is included here as Table 6<sup>3</sup>. As he explains:

“[Table 6] provides a series of categories where different modelling systems can be placed according to the nature of the treatment of both the land use and the transport components of the larger spatial activity system. The level of sophistication increases moving from left to right and from top to bottom. Some of the current state-of-the-art and state-of-the-practice modelling systems are also indicated.”

		transport							
		four-step (traditional)			aggregate		micro-simulation		
		standard	enhanced	complex	tour	activity-travel	tour	activity-travel	
land use	one-way	factored							
		simple							
		intermediate							
	connect	intermediate							
		market-based							
	integrated	aggregate economic (spatial IO)							
		disaggregate economic (micro-simulation)							

3.3.2 Since the diagram caters for categories of complexity for land-use and transport separately, it is noteworthy that current developments are to the extremes of **both** axes. It is also noteworthy that all the “extreme” examples are from North America.

3.3.3 The contribution from Algiers concentrates on a number of key issues:

- the decision making unit;
- the decision making process; and
- the choice dimensions.

3.3.4 At the same time, it draws some key conclusions on the necessary development of the “Mainstream”:

“The general need to improve travel behaviour modelling, as well as to be able to answer new transportation planning questions, makes it desirable to

<sup>3</sup> An application of the structure identifying key model applications is included in Appendix D.

develop mainstream modelling in a number of aspects. In particular, the following aspects should be given attention:

- Modelling of household interactions, eg as combined individual choices
- Modelling of tour patterns, eg by tour(nontour) combination choices
- Modelling en-route path choices, eg by combining/replacing equilibrium assignment models by micro/meso assignment models
- Enhancement of the range of communication means, eg by adding Internet services
- Allowing preference distributions, eg by drawing from estimated parameter distributions

“These extensions of mainstream modelling seem vital for mainstream modelling to be able to cope with the next decade's planning problems.

“The extensions will, taken all together, require a substantial computing power. But, seen over a decade, and taking the expected development of computing power into accounts, it may be found to be quite feasible. Of course, different aspects will be of different value for different applications, and it may well be that in many cases some parts will be treated in a simpler way.”

3.3.5 On the basis of his own work in the Stockholm context, he concludes that the treatment of the “decision making unit” beyond a single individual is feasible, and that interactions between household members can and should be taken into account. In particular, the approach deals with the competition for the car and its impact on trip chains – effectively the concept of car availability is “dynamic”. Further, the choice of car ownership depends on the simultaneous workplace location choices of adults in the household.

3.3.6 Algiers notes that:

“It has been demonstrated in the Stockholm example that household interaction effects exist, and that it is possible to incorporate a number of interactions between household members as extensions of mainstream modelling. It is less clear though, to what extent this actually improves the forecasting capability of models, that is to what extent the forecasts would have been different according to whether interactions are included or not. Credibility is however an important aspect of models, and inclusion of household interactions may add to the credibility of models even if forecasts are only marginally affected.”

3.3.7 In respect to Choice dimensions, he notes:

“An continuing assumption in the mainstream approach has been to assume independence between different travel purposes. This is of course one of the main criticisms from activity-oriented modellers, but it may well be that this to some extent can be incorporated in the mainstream approach.

Research has demonstrated that it is possible to extend the trip generation modelling from models of purpose specific frequencies to frequencies of combinations of trip purposes (or, as would be more appropriate to put it, combinations of activities). Such an approach adds of course to the computational task, but is fairly straightforward. ....

“Trip chaining (the lack of which has also been criticised by activity-oriented modellers) .... is another extension to mainstream modelling that research has demonstrated to be possible to include in the mainstream approach, for example by the inclusion of trip type choice and the concept of a secondary destination, conditioned on the movement between two other points, such as home and work .... Such an extension, will increase computations substantially (as is the case for many others as mentioned earlier). This may have been an obstacle earlier, but as computers grow faster this will change. So far, the obstacles has been circumvented by simplified implementation of such extensions. The gain is a more realistic modelling of travel behaviour and its economic and environmental impacts.”

- 3.3.8 A brief review of the work in Portland, Oregon is presented. Overall, there is thus a clear impression of convergence towards some key aspects of the activity paradigm, as indicated earlier.
- 3.3.9 On the specifics of Activity Analysis, Axhausen notes that the core of the approach is ambitious and that “even today [it] cannot be realised in its totality. The number of endogenous variables, the long timeframes of analysis and the social context are just too complex for today’s analytic modelling tools; even the descriptive work does not fully live up to the demands, but for a large part because of the lack of suitable data sets.”
- 3.3.10 However, he notes the considerable overlaps between the transport modelling and activity analysis communities, and argues that “It is the recent progress in choice modelling .... in the modelling of systems of simultaneous equations ... and in gaming- and computer-based surveys, which is slowly allowing the activity-based researchers to address their original research programme head on.”
- 3.3.11 Again, with respect to modelling, he suggests that “The recent work in Portland, Oregon..... as well as ....work in the UK .... has shown that these approaches can be implemented for practical policy analysis. They will merge with approaches .....which derive directly from the early German work on activity-chain based simulation”. His optimistic forecast is that:
- “The fruitful interaction between choice-modelling and the activity-based approach will continue in development of these models, with activity-based research continuing to highlight behavioural omissions in the choice-models. One important direction will be the incorporation of household interactions, already mentioned above.”
- 3.3.12 On activity **scheduling**, Axhausen concludes that there is rather more work to be done. He makes a number of key points:

“The next generation of research tools will integrate models of day-by-day activity generation, of daily activity scheduling with models of activity execution and of traffic flow and route choice. They will also incorporate day-to-day learning to generate the paths of systems through time.

“The scheduling models, as all simulation models, will have to be integrated in appropriate user environments, which help the analyst in the application of the tools by specifying the required experimental designs, by collating the relevant measures-of-effectiveness from the outputs and by estimating correct summary statistics and response models from the simulation runs.

“The parallel development of dynamic equilibrium models of travel demand and assignment and of comprehensive path-dependent scheduling models should be seen a chance for collaboration and not as a choice of either/or.”

3.3.13 Note that there is a clear link here to the “Dynamic” models discussed earlier, both in the concept of scheduling itself and in the possibility of incorporating learning or adaptive behaviour.

3.3.14 Overall Axhausen’s conclusion in relation to model development is as follows:

“The bottlenecks for these developments are intertwined: a) the willingness of the research councils and planning agencies to invest into data of suitable quality to support the model development; b) the dissemination of the research results to the practitioners and their professional development and c) the necessary time for the practitioners to become familiar with the approaches and models. Depending on the direction of the dynamics both a virtuous circle of progress or a vicious circle of stagnation is a possibility for the future.”

3.3.15 On the land-use front, Hunt begins by emphasising the potential broad scope of land use, which “has now expanded to include any component of the spatial activity system not directly represented in a transport model...” Given the key topics of residential (and other) location choice, as well as demographic and migration aspects, the potential for convergence with activity analysis is evident.

3.3.16 In relation to Table 6,

“The lower right corner ... represents the nature of treatment that is just starting to emerge in one or two current large-scale, multi-year projects of a partly research and partly development character that are intended to stake out a long-term view. This lower right corner can be taken to indicate the general direction for more widespread practical work for the next ten years or so.

“Alternative possible ‘development trajectories’ representing programs of model development with one or more interim designs working towards final design can also be shown on [Table 6]. In general it is expected that the trend in development will tend to be more moves to the right rather than moves downward given the much greater level of acceptance of modelling

within the transport field and the resulting greater levels of funding and activity generally.”

3.3.17 He makes some important predictions and qualifications:

“It is expected that the practical work on land use modelling overall over the next ten years or so will be comparatively ambitious in that attempts will be made to widen the scope of representation of actual behavioural mechanisms. This is based on the expectation that:

- there will be continued and perhaps even increasing pressure to use these models to address a wider range of issues;
- there will be much more powerful computing available at lower prices; and
- there will be more widespread use of micro-simulation consistent with both (a) the ongoing development and availability of object-oriented programming and (b) the appeal of such techniques arising from their ability to address a wider range of issues.

“If history repeats itself, then there will be a failure to meet the unreasonably high expectations that will develop, and then there will be little faith in land use modelling and there will be a lull for a period of time. Therefore, it is important to ensure that expectations are kept reasonable – and that this sort of modelling is not ‘oversold’. The reality is that land use modelling and land use and transport interaction modelling are extremely ambitious, particularly when attempts are made to widen the scope of representation, and they are almost certain to produce forecasts that do not match reality. There are just too many large ‘external’ effects and the system is too complex for close matches to be likely.”

3.3.18 He continues:

“The big change, which in some sense amounts to a revolution, is the shift to a microsimulation environment. This is occurring more on the transport side at the moment, but will gather on the land use side also, primarily on the household side. This will allow the explicit representation of all sorts of causal/behavioural mechanisms and relationships that have not been considered directly to date...”

3.3.19 Despite the considerable appeal of microsimulation, Hunt notes some potentially serious technical obstacles which “relate to the elements of the modelling framework and techniques, including:

- model parameter estimation and related calibration techniques that are too difficult or too complex for widespread practical use;
- handling the issues that arise with the non-repeatability of a micro-simulation dynamic representation based on Monte Carlo approach: The use of dynamic simulation rather than equilibrium could introduce chaotic behaviour. This could be seen as an enhancement that would make the



model more realistic and would allow the consideration of such chaotic behaviour, and the conditions that bring it about; but it would also significantly increase the complexity of the analysis and the time required for analysis work. Multiple model runs might become essential in analysis;

- lack of an appropriate graphic user interface that provides an effective screen to sift out what is relevant from the full range of output; and
- model run times and related turn-around times that are longer than (unreasonable?) expectations.”

3.3.20 He also notes a number of what he refers to as “support obstacles” which “...relate to the things required in order to facilitate the development and practical application of future land use models, including:

- limited funds for research and development;
- limited funds for practical application work;
- lack of required / appropriate data;
- insufficiently educated modellers and related staff;
- insufficient time for practical application development effort; and
- lack of an appropriate modelling focus in the culture of land use planning and/or transport planning – so the need is not perceived.”

3.3.21 Computing power is not expected to be an effective limitation; rather, it is expected that there will continue to be substantial increases in computing power for decreasing costs. The other factors listed above are much more likely to limit the more widespread development of more sophisticated combined land use and transport models.

3.3.22 The lack of willingness to fund research and development effort and practical application work that gives rise to many of the support obstacles listed above arises for the following reasons:

- a risk-averse perspective that discourages trying novel approaches;
- suspicion (possibly based on experience) that such modelling cannot be sufficiently accurate to be useful or that the benefits of such modelling are so uncertain that the costs are not justified; and
- assessment that the resources are better spent elsewhere.

3.3.23 These remarks are highly pertinent in this context, and need to be constantly kept in mind. They are also a useful summary of the entire discussion about Modelling Possibilities.

### **3.4 Further Discussion of Microsimulation**

3.4.1 A detailed reading of the three contributions summarised in the previous section confirms the importance of microsimulation. Microsimulation is an attractive and

promising technique, and is being incorporated into both activity model and dynamic model systems. As we noted earlier, it is well adapted to “rule-based” approaches, and can be used as a device to make headway with analytically intractable calculations (such as multiple integrals). Confronted with a large set of possible complex alternatives, it has the facility (apparently) to allow some determination of choice, as compared to the multiple probabilities delivered by the discrete choice approach. Added to this is its apparent ability to mimic “real life” behaviour.

- 3.4.2 The caveat is, of course, in the “apparent” qualification. The statistical properties of complex microsimulation systems are under-researched (and there is a concern that to make proper allowance for them might move the computability from the feasible to the infeasible<sup>4</sup>). This has already been alluded to in the remarks by Hunt quoted above.
- 3.4.3 A clear discussion is provided in a recent paper by Bradley *et al* (1999). In their useful Table 2 which we reproduce here as Table 7, they present a two-way classification of Modelling Approaches vs “Application Approaches” (the latter denoting, essentially, what we have described as techniques):

Approaches	Zonal enumeration	Sample enumeration	Stochastic simulation
Trip-based	TYPICAL	Possible	Possible
Tour-based	Possible	TYPICAL	Possible
Activity-based	Possible	Possible	TYPICAL

**Table 7 Transport modelling approaches and techniques**

Source: Bradley *et al* (1999)

- 3.4.4 As Bradley *et al* make clear, the choice of technique is partly based on past practice. The **sample enumeration** technique has evolved with the use of so-called disaggregate hierarchical transport models, where the product of the conditional probabilities relating to differing levels of choice is typically carried out at the level of the individual rather than at that of the zone (the **zonal enumeration** method of traditional four-stage and other models). However, “sample enumeration can work with large samples, or else with smaller samples with expansion actors to weigh up to the total population. At some intermediate stage, the two approaches can come to resemble each other.”
- 3.4.5 The authors go on to note that “In stochastic microsimulation, the key difference is that instead of enumerating all possible combinations of model outcomes and multiplying probabilities, a single outcome is predicted from each model, drawing

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<sup>4</sup> In particular, microsimulation involves the use of random numbers in predicting which one alternative the traveller (say) will select in making each decision (hence the alternative name, Monte Carlo simulation). In some applications, the final forecast is made by averaging the results of a series of simulation runs. The circumstances in which this is necessary, and the number of runs which have to be averaged if so, need further investigation.

randomly from the model probabilities... This introduces some random sampling error into the forecasts, which decreases as the number of households simulated increases. Conceptually, each random draw can be thought of as the choice made by a single person or household, given the odds predicted by the model. ....this approach typically uses large samples with little or no expansion...”

- 3.4.6 The differences are both theoretical and practical. Bradley *et al* conclude that “Along **major overall indicators** [emphasis added], the results from different microsimulations using different random number sequences did not differ by more than 1 or 2 percent from each other or from the sample enumeration results.” However, this is not, in our view, much more than a demonstration that the system has been correctly implemented. In practice, models will be used to predict changes which are relatively small in comparison with the overall transport system. The much stronger requirement is to show that the statistical properties of the predicted change can be made independent of the random number sequences.
- 3.4.7 The practical issues relate, of course, to computer storage and run time. Although these have increased dramatically, and further increases can be expected, the Portland models reported by Bradley *et al* still require 30 hours for a model run. And, as noted earlier, there remains a research agenda to justify the level of detail which these models include.

### **3.5 Other Work within the Transport Research Community**

- 3.5.1 In addition to the assessments of the state-of-the-art which we commissioned in areas where we judged that substantial progress had already been achieved, we were keen to identify other, currently less developed, areas where it is reasonable to hope that, in the longer term, future modelling methods may emerge. Accordingly, we conducted an informal survey of transport research organisations to identify ideas and projects which are seen as possible candidates. We did this by means of an e-mail circular to all members of the Universities Transport Studies Group (UTSG) electronic mailing list, which reaches many of those with transport research interests in consultancy and government, and in other countries, over and above its core membership of academics in UK transport studies departments.
- 3.5.2 Because this part of the study is clearly more speculative, we tried to canvass as widely as possible, and invited researchers to indulge in some limited promotion of their own work and that of their colleagues. In doing so, we made it clear that interested parties should attempt to justify the likely value and use of the approach being developed, and also give some indication of the likely timescale before the approach would come to fruition.
- 3.5.3 Clearly, this is not a scientific survey, and we are entirely dependent on organisations to respond. There may be significant fields of endeavour (especially outside the existing transport research community) which we have either failed to reach or where there has been insufficient incentive to provide the information we required.

- 3.5.4 The results were mixed. Some responses were merely interested in establishing links with a view to being kept informed of progress, and others had the intention of promoting novelties which were at best tangential to our investigations.
- 3.5.5 Of the more positive contributions, some material clearly fitted within existing approaches and have been referred to above. We received a useful communication from Ben Heydecker of UCL relating to the restricted but highly important area of dynamic assignment: a summary plus a list of references is contained in Appendix E. Paul Rosen of the University of York outlined proposed research into factors affecting cycling, with particular reference to social factors (such as requirements or expectations regarding dress at work, and the implications of this for cycling in hot/cold/wet weather); whilst interesting, it appeared that this analysis could be carried out (and possibly implemented as a model) using existing disaggregate methods within the mainstream, and did not constitute a new approach.
- 3.5.6 The most detailed relevant responses were received from
- members of the AMADEUS research program being carried out by a consortium of Dutch University research departments under the co-ordination of Professor Harry Timmermans, Urban Planning Group, Eindhoven University of Technology; and from
  - Kara Kockelman of the University of Texas at Austin in relation to a proposal "Towards Behaviorally-Consistent Integrated Transport-Land Use Models, " to Support Infrastructure-System Decisions" .
- 3.5.7 Clearly, both of these fit in to, rather than expand, the range of areas which we have already identified.
- 3.5.8 In relation to the AMADEUS work, the following description is of relevance:
- "The development of activity-based models of transport demand constitutes one of the most rapidly growing fields of interest in transportation research. Many different modeling approaches have been advocated..... These models have in common at least two problems. First, none of the models addresses multi-modal transportation systems in a considerable amount of detail. Transport modes are usually linked to trips; the possibility of more than one transport mode during is trip is typically excluded. This is a shortcoming as multi-modal transportation systems are viewed as a potential solution to current urban transportation problems. Little is however known about the impact of multi-modal systems on activity schedules and related travel patterns. At the very least, existing activity-based models need to be adjusted to incorporate transport mode chains embedded in multi-modal systems.
- "Secondly, current activity-based models tend to focus on the explanation and prediction of observed, cross-sectional activity-travel patterns. Modeling the dynamics of activity patterns is still scarce, although some teams have announced plans into this direction ..... These plans tend to focus on the short-term dynamics, that is the problem of (re)scheduling activities as a function of network congestion or unexpected events.

Attempts of modeling mid-term or long-term dynamics are virtually lacking, at least in the activity-based tradition.

“To fill this gap, a consortium of universities participating in the Netherlands Graduate School of Urban Research (NETHUR) decided to join forces in a collaborative effort to develop a comprehensive and integral modeling system that allows one to assess the long-term, mid-term and short-term dynamics of multi-modal transportation systems on activity and destination choice. The research program, called AMADEUS, is funded by the Dutch Organization of Scientific Research (NWO) for a period of four years.” (from Arentze *et al*, 2001[?])

3.5.9 The programme started last year, and according to the co-ordinator, can be seen as an extension of ALBATROSS (reviewed in the paper by Axhausen as one of the few models which had made significant recent progress with activity scheduling).

3.5.10 The proposal by Kockelman has recently been accepted, and will run for four years. A brief description of the model structure is as follows (taken from the proposal):

“The system of equations characterizing the sub-models will require simultaneous evaluation, as the market seeks a general equilibrium. A multi-level optimization strategy will accompany this equilibration. The top level of this optimization problem represents infrastructure provision, traffic management policies, and land-use regulations by engineers, planners, and policy-makers who seek low-cost, environmentally sustainable production and needs fulfillment for the region’s inhabitants. The second level portrays the choices of developers and land owners who predict the demand for certain land uses and strive to offer the rent-maximizing combination. A third level depicts the location and production decisions of profit-maximizing businesses and utility-maximizing households, subject to budget, network, and land use constraints. And the fourth and lowest level solves for the congested-network travel-time conditions resulting from “shortest path” trip-making equilibration. Notably, the entire model will be subject to a variety of practical constraints, including the durability of transport infrastructure and building stock, prior zoning designations, technology, and infrastructure capacity.”

3.5.11 It is recommended that a “watching brief” be extended to both these projects.

3.5.12 A list of all respondents is given in Appendix F.

## 4 CONCLUSIONS ABOUT MODELLING POSSIBILITIES

- 4.1.1 Looking first at the range of possibilities, we have not identified any “new wave” outside the existing approaches which we listed in our Inception . Our assessment is that most advances are taking place either within those four existing **approaches**, which we have examined in some detail, or in the realms of **techniques** which can be employed in implementing those approaches. In some cases, the advances are not so much new ideas as older ideas that have finally become feasible owing to increased computing power.
- 4.1.2 We noted at the outset that our emphasis would be on travel modelling rather than on “background” variables such as car ownership, in particular, or population and employment characteristics. Although these merit attention in their own right, especially in relation to continuing use of the mainstream approach, they are being increasingly dealt with within some of the wider alternative approaches. Indeed, the convergence of state of the art approaches, which emerges strongly from the previous Chapter, is tending towards a more “holistic” account of all aspects of the transport system within a general socio-economic context.
- 4.1.3 In relation to car ownership, we recognise that quite apart from the prediction of household car ownership and hence the impact on car availability at the individual level, there is a growing requirement for answers to questions about ownership of cars by type (eg diesel/unleaded/ electric/hybrid) and the possible impact of local policies eg access to certain areas only for zero-emissions vehicles. These issues will need to be addressed whatever general decision is taken on the modelling of Travel Demand.
- 4.1.4 Although the strength of the relationship remains relatively weak, there is increasingly compelling evidence that car ownership can be impacted on by changes in accessibility and is therefore partly network- (and land-use-) dependent. The holistic modelling approaches are clearly well-placed to incorporate this.
- 4.1.5 While the convergence of different approaches encouraging, we have some concern that a “step change” in complexity is taking place in some of the “leading-edge” projects, without much attention to the contribution of individual components. We appreciate that those undertaking such projects are probably responding to complex briefs which require them to advance on many fronts at once. However, we envisage that our recommendations will need pay more attention to the principle of **parsimony**. It is important to find the appropriate balance between oversimplicity and excessive complexity, bearing in mind the requirements for the state of practice (as opposed to state of the art). The complexity (or perhaps the apparent complexity) of models is an important issue in relation to considering how they can be brought into general use. Given the wide

gap which already exists between typical UK modelling practice and the state-of-the-art, this is of considerable concern.

- 4.1.6 There is also a long-standing issue relating to model **validation**, which interacts with principle of parsimony. While ever-increasing complexity may seem to be justified in the name of a more realistic description, it is *potentially* in opposition to the kind of confidence-building that depends on a) a comprehensible model structure and b) some demonstration that the model's predictions accord with actual outturns. This will need to be considered further.

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