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REVIEW OF LAND-USE/TRANSPORT INTERACTION MODELS

David Simmonds Consultancy in collaboration with
Marcial Echenique and Partners Limited

and

REVIEWS

Dr John Bates
Professor Jan Oosterhaven

Reports to The Standing Advisory Committee
on Trunk Road Assessment

October 1999
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Foreword

The main part of this book contains a report prepared for SACTRA by David Simmonds Consultancy in collaboration with Marcial Echenique and Partners Limited, "Review of Land-Use/Transport Interaction Models". The main text of the report is accompanied by an extensive set of Annexes, which have a separate Contents section starting on page 75.

Following on from this are two separate commissions, by Dr John Bates and Professor Jan Oosterhaven, both of which are reviews of the main document.

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CHAPTER 1

Introduction

1.1 Introduction

This Report has been prepared for the Standing Advisory Committee on Trunk Road Assessment (SACTRA) by David Simmonds Consultancy (DSC) and Marcial Echenique & Partners Ltd (ME&P), in response to a Brief issued by the Department of the Environment, Transport and the Regions on 14 April 1998. The Brief called for a review of land-use/transport interaction models, to assist SACTRA in formulating advice on possible improvements to practice in appraisal of the economic development impacts of transport projects.

An Interim Report was submitted in June 1998. Since then, both the range of models considered and the discussion of them have been extended. In addition, the material has been substantially reorganized, into the structure described below.

1.2 Structure of the Report

The report is in two sections.

This section contains the report itself. Chapter 2 outlines the scope of land-use/transport interaction models in terms of the representation of different markets. Chapter 3 introduces a classification of such models, and outlines briefly the particular models we have reviewed for this Report. Chapter 4 compares the models with one another, and begins the process of comparison with the Venables and Gasiorek model framework[1], which SACTRA have been considering during their recent work. Chapters 5 and 6 discuss various issues raised in the Brief and other correspondence. In Chapter 7, we attempt to draw some conclusions, particular to summarise our answers to the Committee's questions.

The second section presents more detailed information on the key models as a series of Annexes. The intention is that this main section can be read as a stand-alone document, whilst the Annexes provide additional information for readers who require more detail of the individual models.

1.3 Acknowledgements

We would like to record our thanks to the developers of several of the models discussed, for their help in supplying information to extend or update our knowledge of the field, and to a number of members of SACTRA who commented on earlier drafts of this report.

1 See Venables and Gasiorek (1999).

CHAPTER 2

The scope of land-use/transport and other models

The words “land-use” in the name “land-use/transport interaction model” are potentially misleading. The “land-use” components of the models known by this name represent, between them, many different aspects of human activity. Most of these models do represent the amount of land used for different purposes in different places, but in most cases this representation is only a small part of the overall “land-use” modelling. Moreover, in some cases, the physical use of land is not considered at all.

A different and more exact name for the intellectual and computational tools currently known as “land-use/transport interaction models” would probably be helpful to all concerned. This Report, however, is not the place in which to debate alternatives. We try instead to indicate what it is that “land-use/transport interaction models” do, starting by reference to the conceptual model shown in Figure 2.1.

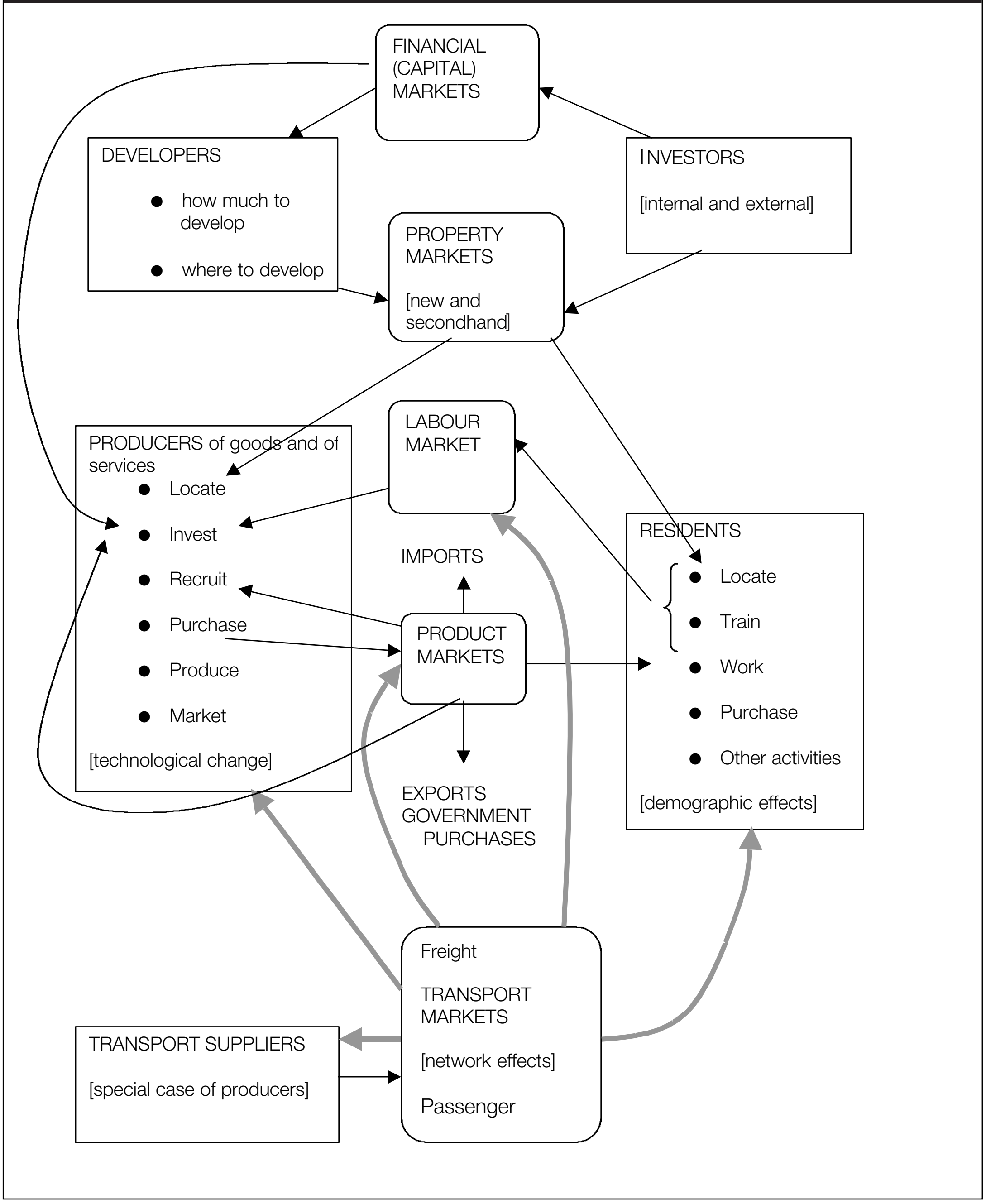
This diagram represents a partial view of the world from a “spatial-economic-transport” point of view, in terms of categories of economic “actors” and the interactions between them, which represent “markets”. The main categories of actors – apart from government bodies – are indicated by boxes with square corners. The box on the right-hand side represents “residents” of the area under consideration. Opposite is the category of “producers”, which includes all suppliers of goods and services in the area. Two special categories of “producers” are distinguished by separate boxes:

- transport suppliers (bottom left); and
- developers (top left).

These are picked out because the products and services that these actors supply are of particular interest to us. The final category of actors included is that of “investors”, in the top right. In the conceptual model, this includes all those investors who may invest in the area under consideration, many of whom are resident outside the area itself.

For clarity, we have not attempted to show within the diagram that many individuals are actors in more than one category – for example, self-employed persons are producers as well as residents, and many residents are also investors. One of the most important “actors”, government of all levels, is omitted, even though its intervention through regulation, taxation and investment is an actual or potential influence on almost all the decisions considered. Much of the development of operational models has been led by the need to consider the impact of such interventions, given the behaviour of all the other actors involved.

Figure 2.1: **Actors and markets in land-use/transport models**



The lines on the diagram show the major interactions between different categories of actors, classified so as to identify the main "markets" in factors, goods and services. The directions of the arrows on the diagram are such that:

- the arrowheads show the delivery of a factor, good or service; and
- payment for that factor, good or service goes in the opposite direction to the arrow.

Information also flows in *both* directions along each of the relationships indicated by arrows. This represents the often very partial information which people and firms obtain from the interactions with the market. Other information is obtained in other ways, which may themselves involve purchasing goods and services (eg market research reports, special surveys, newspapers with job and property advertisements, etc).

The five markets are, from top to bottom of the diagram:

- the financial market(s);
- property markets;
- labour markets;
- product markets (including both goods and services); and
- transport markets.

Note that the first three of these are markets in the conventional factors of production (capital, land and labour), and that the markets in transport are a special case of the markets in services. We have not attempted to separate categories of goods and services that are delivered via non-market mechanisms, such as, for example, public (state) education, and there are other whole sub-systems, such as taxation, welfare and benefits, which affect the behaviour of actors. The scope of the diagram as it stands is simply that which seems helpful to the discussion of "land-use/transport interaction models". For this discussion, we have however included the possibilities that products may be:

- exported;
- consumed by the government or;
- used in fixed capital formation (the arrow from product markets to the "Invest" action of Producers), and also that they may be;
- supplied by imports to the economy under consideration as well as by local production.

The bold lines linking the transport market to the rest of the system emphasise that transport is generally a "derived demand", derived from some other aspect of the economy. In the diagram, the derivation of demands is split into five segments:

- transport demands associated with product markets, that is, with the delivery of goods and services (through the movement of goods and persons, including consumers going to purchase goods or services) to intermediate or final consumers;
- transport demands associated with labour markets – mainly the movement of persons travelling to work;
- other travel demands associated with the activities of producers – these represent all business demands, mainly for passenger travel, not directly associated with trade in goods or services (eg travel to conferences, to internal company meetings, to meetings with regulatory bodies, etc);
- residents' travel demands other than travel to work or to obtain goods and services, ie all other personal travel; and
- transport demands associated with transport supply itself (eg the significant proportion of rail freight which is generated by maintenance and renewal of the railway itself).

The bullet points listed under some of the "actor" headings are general descriptions of key types of decisions that have to be taken by these categories of actors. The conduct of business by producers is generalised into:

- where to locate the business unit;
- investment in the unit – how much to invest, in what equipment;
- recruitment – what categories of staff to employ, how many, for what hours, at what wage rates, etc;
- purchasing – what intermediate goods and services to purchase, from whom;
- production – how much of what to make and when; and
- marketing – which markets to try to sell in, what to do to achieve this, etc.

This is of course a largely artificial break-down of business decision-making: many decisions, particularly major ones, will deal simultaneously with most or all of these areas. The classification does however seem helpful in relating organizational response to different markets in goods, services and factors of production (and hence, since a lot of analysis is conceived in terms of markets, it seems helpful in relating to other research).

For residents, all human life is condensed into five headings:

- where to locate (and hence what land and floorspace to occupy);
- training – what (if anything) to do to obtain/maintain employable skills;
- work – whether or not to work, for whom, doing what, when, etc;
- purchasing – how to spend (or save – note link to investors) income derived from work or other sources; and
- other activities – everything else.

Note that the first three determine each person's involvement or otherwise in the labour market, and hence collectively the "labour supply", whilst "labour demand" is determined by the location and recruitment decisions of producers.

The diagram, and the discussion of it, could of course be elaborated endlessly, and we emphasise that it is a partial view of the world. As it is currently drawn, we refer to just a few other influences on activities and decisions, indicated in square brackets. These are:

- technological progress as an "exogenous" influence on producers (in the sense that even if firms are technological leaders and innovators in their particular fields, they are strongly influenced by the development of technology in other aspects of the economy);
- natural demographic processes (ageing) and social effects (marriage/cohabitation, separation) on residents and their grouping into households; and
- network effects (congestion) in the transport system (as distinct from the deliberate responses of transport operators and suppliers).

The diagram is used later in this Report to help us to identify both:

- which parts of this conceptual universe are represented in different models; and
- which kinds of decisions or responses, of which categories of actors, are represented in those models.

The distinction between these two points is important. As is shown later, many models of interest are fairly "extensive" in that they represent, for example, the market in products, but are at the same time relatively "poor" in their representation of decision-making, with few forms of response being explicitly represented.

To give some pertinent examples of different kinds of modelling, we can broadly characterise some relatively common models:

- "pure" transport models as representing (some of) the transport market, often with both demands and transport supply taken as fixed;
- demographic models (eg cohort-survival models) as representing the exogenous element of change in residents;
- residential location models as representing the location of residents (with more or less detail of housing occupation and of accessibility);
- input-output models as concentrating on the chains of relationships in product markets and so on.

The present review is concerned with land-use/transport interaction models, which in terms of the diagram can be defined as those models which include:

- some form of spatial representation of producers, residents, and transport supply (not necessarily traced back to transport suppliers);
- links from producers and residents, and/or from labour and product markets, to transport markets, as the main or only process by which transport demands are derived; and
- links in the opposite direction, from the transport markets to the activities and markets which use transport, such that changes in transport have at least some impact on some decisions or responses of producers *and* residents.

It follows that land-use/transport interaction models must, by this definition, represent the main activities which, in the real world and in the conceptual system, constitute the uses of land, but they do not necessarily represent the use of land itself. We discuss later the major differences between "urban" land-use/transport models, which concentrate on issues related to passenger transport in predominantly urban areas, and "regional" land-use/transport models, which concentrate on issues related to longer distance movement typically of both passengers and freight. The following chapter outlines the main operational approaches to creating such models (with particular reference to the treatment of time, which like space is in our opinion critical but is only implicit in the diagram). It identifies the particular examples of models which we consider. In Chapter 4 we can then examine how these models represent the actors, the decisions and the markets indicated in Figure 2.1.

CHAPTER 3

An overview of the models in the review

3.1 Introduction

Wegener (1994a) in his comprehensive review of operational urban modelling activity pointed out that although the groups actively involved in developing land-use/transport interaction models are widely scattered across the globe, they nevertheless form an effective community. Within this community, different teams are generally aware of each others' approaches and activities, and many of the key individuals are personally acquainted. Given that the team responsible for the present review are very much part of that community, both individually and collectively, we have not set out to conduct a formal literature search, but have concentrated on updating our knowledge of models already known to us.

3.2 Classification of models

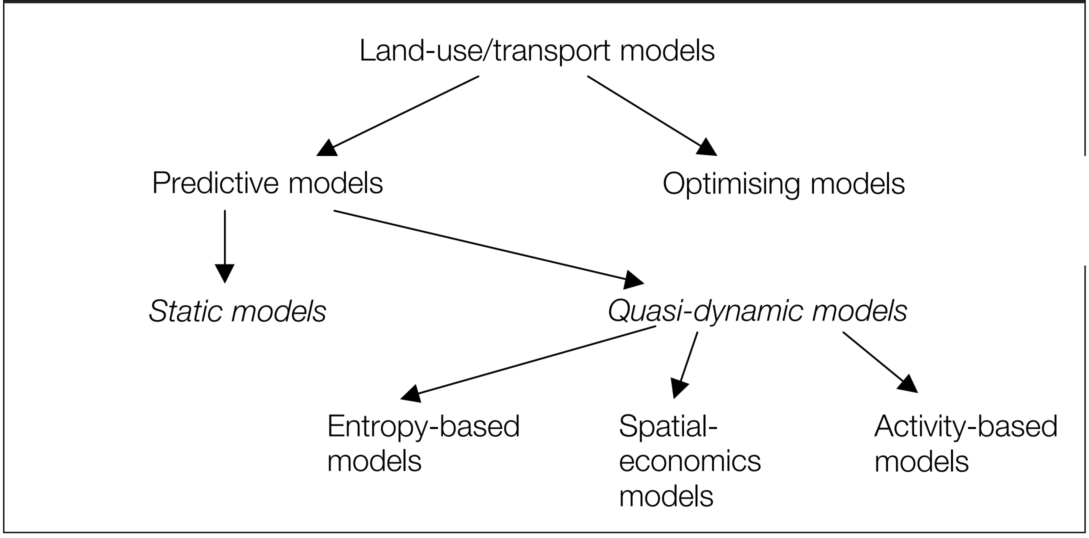
For this review, as for previous model comparisons, we divide models into five groups as shown in Figure 3.1.

The first layer of the tree, starting from the top, separates out a group of models whose purpose is to optimise urban systems rather than to predict their behaviour. Such models are intended as tools which can find a "design" to optimise a particular function, and are therefore quite distinct from the majority of models which respond to a "design" input by the user. These optimising models may be informative for research and long-term planning, but in general they are difficult to link to the practical planning problems of individual cities or regions. Accordingly, we will not consider them any further.

The second layer of the tree distinguishes between *static* and quasi-dynamic models. Static models represent a single point in time, whereas quasi-dynamic models run for a series of time periods, with transport changes generally taking one or more such periods to have an impact on land-use. Much of the early work in the evolution of land-use models consisted of static models which attempted to predict the location of certain variables taking other variables as given (see, in particular, Lowry, 1964, and the whole range of Lowry-inspired models considered in Batty, 1976). Such models obviously cannot represent in any "realistic" way the processes of urban change which, by their nature, take time to react to any changing situation. For this reason, static models had ceased to represent the state-of-the-art by the time the ISGLUTI project began around 1980 (see note on ISGLUTI, following the References). Static models have however retained some relevance to cases where a dynamic land-use/transport model is unaffordable.

Returning to Figure 3.1, it is rather more difficult to make distinctions within the remaining category of quasi-dynamic models, because each such model is complex and typically contains a range of elements which could cause it to be classified in different ways. The following classification has been used in a number of papers

Figure 3.1: **Classification of Models**



(starting with DSC's work for the APAS urban models review (European Commission, 1996)) and seems to have proved useful without provoking recriminations from other modellers. It identifies:

- models based originally upon the analogies with statistical mechanics ("entropy") pioneered by Alan Wilson in the 1970s;
- models based primarily upon the integration into a spatial (multizonal) form of separately developed (and often non-spatial) economic models; and
- models based primarily upon representation of the different processes affecting the different types of activities considered.

Note that in this Report we use the term 'quasi-dynamic' to describe models which urban modellers would call "dynamic". These models have a treatment of time, simplified into discrete periods, and at least some of the relationships within the model respond to values of variables from previous time periods. This is different from the traditional economic meaning of the term "dynamic", which implies that economic actors' behaviour can fundamentally change in response to changing conditions.

3.3 Models discussed in this review

This chapter outlines the range of available models following the organisation of models presented above. It discusses all the examples of models that we have considered in this review.

STATIC MODELS: DSCMOD, IMREL AND MUSSA

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

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

The category of static models can be divided into:

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

The IMREL and MUSSA models are representative of the single-input approach, whilst DSCMOD is representative of the two-input approach. DSCMOD has been developed by DSC since 1990 for the practical objective of adding a land-use dimension to what would otherwise be transport-only studies. MUSSA (developed by Martínez and colleagues in Chile) is primarily a research tool. IMREL (developed by Anderstig and Mattsson in Sweden) has been used for both purposes. These three models are described in more detail in Annex A. At least two transport modelling packages (TRACKS and TRANSTEP) have offered facilities to build similar static models, in addition to the many static models which were developed in the 1960s and 1970s.

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

These models are generally urban models. However, a regional employment version of DSCMOD (Simmonds, 1992; Simmonds and Jenkinson, 1993) has been developed which represents only employment and uses a measure of economic potential (accessibility factored by zonal employment) to relocate jobs.

MUSSA (Martínez, 1992) is similar to the Anas models discussed below in adopting a unified economic framework, and is closely connected to a four-stage transport model. Unlike any model considered so far, it represents firms rather than employment with demand for space determined by a willingness-to-pay measure. Households attempt to maximise their consumer surplus, while developers attempt to maximise the price paid. MUSSA is not however available as a commercial package.

ENTROPY BASED MODELS: LILT

3.3.2 LILT (Leeds Integrated Transport package, Mackett 1979, 1983) is the main UK model of this type, and has been applied in Leeds, Dortmund and Tokyo (as part of ISGLUTI), and several other UK urban areas. However further developments of this model have ceased. A similar, but simpler, US model, DRAM/EMPAL (Putman, 1995) has been widely applied at the urban level in the USA.

LILT allocates exogenous totals of population, jobs and employment. It is based around a Lowry model formulation, linked to a traditional four stage transport model. Households are allocated on the basis of travel to work, following a spatial interaction framework. Employment is allocated on a different basis depending upon whether it is primary, secondary or tertiary, the former allocated exogenously, the latter two allocated on the basis of accessibility and population distribution. Note that market processes are not modelled, and linkages between economic sectors only figure via the basic/non-basic distinction. It models a closed system. More details of LILT can be found in Annex B.

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

SPATIAL-ECONOMIC MODELS: MEPLAN AND TRANUS

3.3.3 MEPLAN (Echenique et al, 1990) and TRANUS (de la Barra, 1989) are both commercial packages developed from a set of models devised at the Martin Centre at the University of Cambridge[2]. Both MEPLAN and TRANUS have been applied in policy and research studies both in the UK and abroad since the 1980s. Each package includes both a land use model and a multi-modal transport model, and is usually implemented as a quasi-dynamic model. There are many similarities in the broad approach adopted by the two packages, to the extent that for policy analysis purposes they can be treated as one. This review concentrates on MEPLAN, both because this information is more readily available and because (as far as we are aware) TRANUS is rather less developed in its treatment of economic relationships.

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

In urban applications of MEPLAN (such as LASER – see Williams, 1994, or ME&P, 1995) particular attention is paid to residential location and the journey to work, shopping and schools. For regional implementations (e.g. EUNET, also outlined in Annex C), emphasis

2 For an outline of the history of these models, see Hunt and Simmonds (1993); for more detail, see the 1994 special issue of the journal *Environment and Planning B* containing urban and regional modelling papers from the Martin Centre 25th Anniversary Conference (see note to the references).

is also placed upon industrial location and movements of freight from producers to consumers, with explicit modelling of the regional economy.
A new easy to use package MENTOR, designed specifically for local authority use in the UK, is currently being tested. MENTOR is a pure land use package that can be interfaced to existing transport models. It builds on the theoretical structures of MEPLAN but operates at a more detailed level of segmentation of activities and is more straightforward to set up and calibrate. It retains the key characteristic that the distribution of transport demand is explicitly derived from the interactions modelled within the land-use model.

The MEPLAN package, its application to LASER and EUNET, and the MENTOR package are all described further in Annex C.

SPATIAL-ECONOMIC MODELS: METROSIM

3.3.4 METROSIM has been developed by Alex Anas, one of the pioneers in the development of a rigorous theoretical economic framework (Anas, 1982) for urban modelling. It differs from other models in this review by dealing with all the land use and transport choices *simultaneously*, in a micro economic framework. METROSIM (or rather the land use elements of it[3]) is currently being applied to New York in the USA, building upon previous applications of earlier simultaneous residential and mode choice models (Anas, 1995). METROSIM is more comprehensive than previous economic models, (e.g. Anas & Arnott, 1993), representing the property development market and employment location. Note that the model as implemented finds the equilibrium state for housing, floorspace, labour and travel for a forecast year, and is therefore a static model. The package is however capable of operating over time, and we have therefore classified it as a dynamic model. Further detail is given in Annex D.

Several other model development projects are underway in Japan also looking into simultaneous transport and land use choice models, but as yet they have rarely been used in policy related studies, and are not available as packages.

ACTIVITY MODELS: DELTA AND URBANSIM

3.3.5 Activity based models are defined by their focus on the different processes of change which affect activities and the spaces they occupy; they are therefore the complete opposite of general equilibrium modelling. These models tend to be characterised by more detailed segmentation of activities, and more elaborate treatment of both the decision to move and location choice. In contrast to other models, they do not relocate all activities in a time period, but separate the decision to move (which will affect only a proportion of total activities) and the search for a new location. These models also represent demographic change in more detail than any of the models so far considered.

The examples of this type of model are DELTA and URBANSIM. DELTA has been developed by DSC since 1994 and applied to Edinburgh and Greater Manchester. URBANSIM has been developed by Waddell (latterly as Urban Analytics Inc) over

3 It is not clear from the available information whether the integration of the land-use elements of METROSIM with an existing transport model means that the simultaneity of land-use and transport choices is being lost, or that a particular complex integration of two model systems is being attempted. It is possible that the decision on this has not yet been taken.

approximately the same period. URBANSIM is being applied to Eugene/Springfield (Oregon) and is to be applied to the Salt Lake City region[4].

These models are designed to be linked to transport models developed in separate packages[5]. Each of them incorporates a development (construction) model, a demographic model and a random utility discrete choice location model. In DELTA households follow a utility maximising formulation, the market adjusting prices within a time period, while in URBANSIM households maximise a consumer surplus measure and use a bid-choice function derived from the equilibrium type developed by Martínez (1991). The other key difference between DELTA and URBANSIM is that DELTA is incremental, working with the changes in past transport and land use conditions, while URBANSIM is based upon a cross-sectionally calibrated relationship.

One of the characteristics of the focus on processes of change is that the design and calibration of the model (certainly in the DELTA case) draw much more upon other aspects of urban research (in economics, geography, sociology, etc) rather than drawing purely upon other modelling work. Another characteristic is that different processes are likely to predominate at different spatial scales. A regional version of DELTA is currently being developed for application to the whole of the Trans Pennine Corridor. The intention is that this should retain the existing processes of urban change within each of the conurbations and other cities, but that additional processes of migration and of regional economic change will be added to represent demographic and economic interactions between them. These are discussed in slightly more detail in Chapter 6.

More details of DELTA can be found in Annex E. The information available to us indicates that URBANSIM, when fully operational, will be similar in its general characteristics.

ACTIVITY MODELS WITH MICROSIMULATION: IRPUD

3.3.6 The IRPUD model, which has been applied only to Dortmund (Wegener, 1985), bears many similarities to the activity models outlined above (not least because Wegener's work provided much of the inspiration for DELTA). However, it treats households' choices in even more detail. Its most distinctive feature is that it uses microsimulation techniques to deal with the complexity of the migration processes within the housing market submodel. Housing search is modelled in a stochastic framework to generate intraregional migration flows by household category between housing by zone. There are plans to eventually convert the rest of the model to operate using microsimulation techniques, starting with the transport submodel.

4 An application to Honolulu was started, but we understand was never completed, on account of problems in the underlying planning project rather than in the model. The URBANSIM model of Eugene/Springfield has so far been run only as a cross-sectional location model. Its dynamic operation is intended to be calibrated during the closing months of 1998.

5 The nature of this linkage has caused some confusion. Several of the land-use/transport links mentioned in this Chapter (including MUSSA/ESTRAUS and URBANSIM/EMME2) currently require manual intervention to transfer data from one model to another, sometimes on different computers with different operating systems. The DELTA/START models, however, are automatically linked such that a complete forecast of the combined system can be initiated by a single command and left to run without further intervention.

In other respects it is similar to many of the more sophisticated models already described. It contains a full multi-modal transport model. It has market based models for the conversion or supply of new buildings and for the location of households and employment within them. The transport model is an equilibrium model, while the land-use model components operate in incremental steps through time.

Further detail of the model can be found in Annex F. There appear to be no plans to produce a commercial software package based on this application of the model to Dortmund.

3.4 Models excluded from the detailed review

We have excluded a number of models from further consideration on the grounds that they are optimising rather than predictive in nature, as outlined above. Other than these, the only UK model mentioned in our Proposal which we have dropped altogether is MASTER. Although the approach used in MASTER (microsimulation of the processes affecting members of the population) is of considerable interest as a modelling technique, changes in the number or location of jobs are exogenous to the model (Mackett, 1990a, p19). It therefore seems largely irrelevant to the present review, especially in contrast to IRPUD, which does represent employment choices endogenously.

One other model which should be mentioned here, although it was not mentioned in the Proposal, is the Systems Dynamics model recently developed by the University of Newcastle upon Tyne Transport Operations Research Group (see Bell, 1997). The theory of this model is essentially that of a Lowry model, ie one of the very early predecessors to the LILT and MEPLAN families. The use of Systems Dynamics seems to offer no advantage over other approaches to quasi-dynamic modelling whilst limiting the model to a trivial number of zones (two, in the TORG case). This limitation has been apparent for over 20 years.

CHAPTER 4

Descriptive comparison of the models

4.1 Introduction

This chapter and the following two seek to compare and contrast the various models presented, and to discuss their differences and their potentials for further development, in relation to the questions raised by the Committee. Those questions were raised in the Brief and in the letter commissioning this work, and also include some points which we ourselves raised in our Proposal. We identified the following six themes:

1. the need for explicit comparison of the model in terms of their ability to respond to key changes;
2. their treatment of the "two-way road" argument – whether the models will always produce positive changes for additions to the transport infrastructure;
3. their treatment of new jobs versus displacement from elsewhere;
4. whether the models lend themselves to the identification of "benefits" as distinct from "impacts";
5. the comparison of the models with the Venables-Gasiorek framework; and
6. their potential contribution to transport planning in practice, particularly in terms of the resources (including data) required to apply them to particular levels of analysis.

This chapter deals with the first of these issues. Chapter 5 deals with issues 2, 3 and 4. The comparison with the Venables and Gasiorek framework is started here and continues in Chapter 6. Our conclusions regarding the potential contribution of land-use/transport models to planning practice are given in Chapter 7.

For the comparisons to be developed in this Chapter, we have identified three areas of model response which we believe are critical (some of which were identified in the Committee's Brief). These are:

1. the ability of the models to represent the interaction of transport supply and demand;
2. the way in which activities respond to changed transport conditions, including the responses in the land, labour and product markets (ie covering all the actors and markets identified in Chapter 2); and

3 the implications of all the land-use effects for transport (i.e. the linkage which completes the feedback loop).

Section 4.2 deals with area 1, the models' representation of transport supply and demand, and begins consideration of area 2 by outlining the scope of "land-use" responses to transport change. Section 4.3 develops this in more detail of actors and markets. Section 4.4 compares the models' treatment of the influence of land-use change upon transport.

The range of models considered in this and the following Chapters begins with representatives of the main categories identified in Chapter 3, but in many places has been reduced either because insufficient information was available to the authors, or because the entries would have been repetitive. Some of the sections consider only the present authors' model applications, which are sufficiently different in approach and scale to represent much of the variety in the present state of the art.

4.2 The models' responses to key changes

REPRESENTING THE INTERACTION OF TRANSPORT SUPPLY AND DEMAND

4.2.1 Table 4.1 shows the different kinds of transport responses to transport change which are represented in the main models under consideration. The symbols indicate which of six different demand responses will occur in response to each of seven different transport supply changes. It can be seen that the combination of route, mode and destination responses (ie the lower three levels of the conventional four-stage model) is most common. The other responses, time of travel, frequency of travel and car-occupancy, can generally respond directly or indirectly to all the different supply measures listed. The main exceptions are that:

- EUNET and the DSCMOD European model do not consider parking because of the large spatial scale at which they operate;
- the DSCMOD European model does not consider public transport fares (it concentrates exclusively on business travel and works entirely in terms of time and convenience); and
- the public transport components of START and TRAM do not consider route choice within sub-modes of public transport, ie they consider the choice between train and bus, but not which particular bus route the passenger uses.

INFORMATION PASSED FROM TRANSPORT SYSTEM TO LAND-USE SYSTEM

4.2.2 Table 4.2 shows the kinds of information which pass from the transport system to the land-use system within each of the models. The pattern is slightly complicated by differences between models in how the boundary is drawn between the two components. The main difference in theory is between those models where the land-use model is directly influenced by matrix-type (zone*zone) measures and those where the influence is through vector-type zonal measures. DSCMOD, DELTA and IRPUD use multiple vectors of accessibility measures; LASER, EUNET and MENTOR use multiple matrices of disutility and of money cost. LILT uses both vectors of accessibility and matrices of generalised cost, for employment location and for residents' home/job choices respectively.

Table 4.1: Model responses to changes in transport supply

	Roads	Parking (see note 2)	Rail	VOC	Road pricing	Public transport fares	Speed limits
TRAM (for DSCMOD)	FTRMD	FTRMD	FTMD	FTRMD	FTRMD	FTMD	FTRMD
DSCMOD European model (see note 1)	RM		RM	RM	RM		RM
LILT	RMD	RMD	RMD	RMD	RMD	RMD	RMD
LASER	RMD	RMD	RMD	RMD	RMD	RMD	RMD
EUNET	RMD		RMD	RMD	RMD	RMD	RMD
START (Lothian, for DELTA)	FTRMD	FTRMD	FTMD	FTRMD	FTRMD	FTMD	FTRMD
MENTOR (with Cambridge CC SATURN model)	TRMD	TRMD	TMD	TRMD	TRMD	TMD	TRMD
IRPUD	RMD	RMD	RMD	RMD	RMD	RMD	RMD

Key – measure at top of column can modify

F frequency of travel
T timing of travel
R route of travel
M choice of mode
D choice of destination
C co-ordination of trips/activities by individuals

Notes:

1 the DSCMOD European model includes the above effects in calculating accessibility but does not model flows on the network (i.e. it considers transport supply but not supply demand);

2 the level of detail in which parking can be considered varies markedly between the models – probably more so than for other measures.

Of the models considered, DELTA is the only one to consider the environmental impact of transport use (noise, atmospheric emissions) as an influence upon activities (in particular, on household's locational preferences). Another recent DSC review of models found that few if any models consider the environmental or other land-use impacts of transport infrastructure (eg land take in rural areas, or the competition between parking and other land-uses in urban centres).

The table also shows that the main element in all of the links is generalised cost or disutility, whether the matrices are used directly or to calculate vectors of accessibility. This allows the following table to concentrate on the land-use effects of a change in transport generalised cost.

Table 4.2: **Information passed from transport system to land-use system**

Model	Transport measures used to influence location in the land-use model
DSCMOD urban	Generalised costs used to calculate accessibilities.
DSCMOD regional	Passengers: generalised time (excluding money cost) used to calculate accessibilities. Freight: money costs used to calculate accessibilities.
LILT	Zonal accessibility measures (used in employment location) and matrices of generalised cost (used in residents' location/job choice).
LASER	Passengers and freight: O-D matrices of travel disutility (including cost, time, the time uncertainty due to excess congestion, quality of service) and monetary cost.
EUNET	Passengers and freight: O-D matrices of travel disutility (including cost, time, the time uncertainty due to excess congestion, quality of service) and monetary cost.
DELTA	Generalised costs used to calculate zonal accessibilities. (Use of additional measures based on money costs and on numbers of trips is being developed).
MENTOR	Passengers: O-D matrices of travel disutility measured in generalised time units, monetary cost.
IRPUD	Generalised costs used to calculate zonal accessibilities.

LAND-USE EFFECTS OF A CHANGE IN TRANSPORT GENERALISED COST

4.2.3 In seeking to present the similarities and differences of the models in these respects, we have drawn upon the experience of ISGLUTI, which remains the largest and most thorough exercise in comparison of complex models. The Phase I Report of ISGLUTI (Webster et al, 1988) provided the basis for this table and the following ones, which attempt to show, for the chosen examples of each model, whether particular changes of interest can be modelled:

1 whether certain variables of interest are included;
2 whether those changes will have an impact upon those variables; and
3 if so, whether the impact will be strong or weak, and whether it will be immediate or delayed.

Table 4.3 shows which variables are influenced, immediately or later, by changes in the generalised cost of travel. In the LASER model, a proportion of the effects of an improvement in transport infrastructure is included in the land-use model in the year in which it is opened, to take account of some people adjusting location patterns in the expectation of transport effects, but the full effects on location patterns are only built up after a few time periods. In MENTOR model applications the representation of whether these responses are "now" or "later" or "now+LATER", will differ between applications depending on the way in which the interface to the transport model is designed for that application.

Table 4.4 shows the effect of a transport-induced change in employment in one zone, as an illustration of the nature and timing of responses within the land-use system. This shows clearly that:

- the DSCMOD models are very limited in scope (by intention – they are deliberately limited to relatively simple, impact indicators with minimal interaction between different activities); and

- the equilibrium-oriented models (LASER, EUNET and MENTOR) tend to have more simultaneous linkages than the dynamics-oriented models (IRPUD and DELTA).

4.3 The responses of actors and markets

THE DECISIONS OF ECONOMIC ACTORS IN THE MODELS

4.3.1 We now turn to more detail of how the main models work in terms of the "economic" responses. To organize the material, we refer again to the "actors and markets" diagram introduced in Chapter 2. In that diagram, we identified the major categories of decisions which the different categories of actors could make. Tables 4.5, 4.6 and 4.7 attempt to summarise the way in which these decisions are made by each category – ie what kind of decision (eg where? how much? how many?) is modelled, and what are the influences upon it?

The three Tables deal in turn with the decisions of residents, of producers and of developers. They cover the main ME&P and DSC urban models (ie MEPLAN(LASER) and DELTA(GMSPM), the corresponding regional models (MEPLAN(EUNET) and DELTA (Trans-Pennine), both of which are under development), and the V&G framework. The row immediately below the model headings, with text in italics, shows how the three categories of actors are represented in each model, ie the measurement and classification of the units which make the decisions summarised on the following rows. Those remaining rows correspond to the broad categories of decisions previously identified. Bold type means that a decision process (eg a discrete choice) or response (eg an elasticity) is explicitly represented. Plain type means that the decision is not explicitly represented, but that changes corresponding to that decision occur within the model are derived in fixed proportions from other changes. Hence, to take the first model shown in the first of these tables, the only residents' decisions explicitly modelled in the LASER model are where to live and how much floorspace to occupy. There is no explicit decision of whether or not to work, since this is predetermined by the extended spatial input-output structure. There is no decision about training or other adaption to the available work (nor indeed do any of the other models consider this). Apart from the decision on how much floorspace to occupy, there is no explicit decision about other purchases, or about other activities.

The main point to emerge from these tables is that despite the prominence given to choice theories in discussion of the theory underlying LUTI models, only a small proportion of the "decisions" implied by the model results are modelled explicitly. This is most notably true of producers in the two urban models; production is treated as being almost totally passive, and entirely the result of the interplay between the various locational decisions of customers and of developers. The DELTA models perhaps have a slightly higher proportion of explicit decision-making; this follows unsurprisingly from DELTA's basis in separate models of various key processes, compared with the basis of the MEPLAN models in the comprehensive spatial input-output framework.

The other point reinforced by these tables is that the V&G framework gives relatively more attention to producers' decisions, and very little to any others except for residents' consumption.

Whilst these tables help to clarify the scope (or scarcity) of explicitly modelled decision-making in the various models, it should not be assumed that models with similar entries in one row are similar in operation or assumptions. This is particularly true for residents' location choice, where the MEPLAN and DELTA urban entries respond to very much the same influences. The actual mechanisms used are markedly different: MEPLAN locates all households containing employed residents for a particular point in time, whilst DELTA locates or relocates only new or mobile households, whether or not they contain employed or employable persons, over a period of time during which all other households remain static.

Two limitations of the existing land-use/transport modelling methods may be noted.

The first is that most models concentrate on the relocation of economic activities whose total quantities are either:

- fixed for each point in time in each scenario; or

- varied only by marginal locational change, such as the relocation of certain activities to "external" zones and the consequential loss of multiplier effects.

The EUNET application of the MEPLAN model is the exception, in that it is being linked to a macro economic model which does generate endogenous increases in economic activity due to the productivity gains from cheaper transport.

The second point is that whilst all of the models allow for relocation of at least some economic activities in response to changing spatial demand, none of them currently represent changes in the spatial organization of activities within individual firms. For example, a firm owning three complete car-building factories in different regions may be encouraged by better transport links to convert them into an engine-building plant, a bodywork plant and a final assembly plant, thus achieving economies of scale in each area of activity which might outweigh the increased haulage of part-vehicles. This is outside the scope of existing models (and probably of the statistics on which they are based), though "reorganization" rather than direct increases in efficiency is often cited in empirical surveys of transport impacts.

THE IMPLICATIONS FOR MARKETS

4.3.2 The developers of LUTI models have probably given much less attention than mainstream economists to describing the overall characteristics of the markets they represent; they have tended to focus on the behaviour of the actors (as discussed above) or on the process of calculation involved in running the model. We attempt in the following paragraphs to summarise the nature of each market in various versions of our own models, and (for comparison) in the Venables & Gasiorek approach.

Labour market

MEPLAN (LASER): the treatment of the labour market is embedded in the central spatial input-output equilibrium calculation. This simultaneously determines:

1 the number and location of households (other than wholly inactive households);

Table 4.3: **Effect of a change in transport generalised cost**

Effects of a change in transport generalised cost on:

	Industrial employment location	Retail/service employment location	Housing stock location	Population location	Housing prices/rents	Non-residential prices/rents	Indirect transport demand (via land-use)	Car ownership
DSCMOD Urban (1)	NM	now	X	now	now	NM	X	X
DSCMOD Regional (2)	NOW	NOW	X	X	X	X	X	X
LILT	now	NOW	now	NOW	X	X	now	NK
LASER	now+LATER	now+LATER	now+LATER	now+LATER	now+LATER	now+LATER	now	X
EUNET (3)	NOW	NOW	NOW	NOW	NOW	NOW	NOW	NOW
DELTA (4)	later	later	later	later	later	later	later	X (later)
MENTOR (5)	NOW	NOW	later	NOW	NOW	NOW	NOW	NOW
IRPUD	later	later	later	LATER	later	NM	later	NOW

Notes to Table 4.3:

1 Bristol application
2 European application
3 Trans-Pennine application
4 Edinburgh application (GMSPM differences in brackets)
5 Cambridge application

X = no effect
now = weak simultaneous effect
NOW = strong simultaneous effect
later = weak delayed effect
LATER = strong delayed effect

Information for LILT taken from ISGLUTI Phase I Report, Table 6.10

NM = affected variable not modelled
NK = not known

Table 4.4: **Effect of a transport induced change in employment (in one zone)**

Effects of a change in transport generalised cost on:

	Non-residential rents	Non-residential development (distribution)	Non-residential development (total quantity)	Wages	Location of population	Unemployment and/or participation rates	Car ownership
DSCMOD Urban (1)	NM	NM	NM	NM	X	X	X
DSCMOD Regional (2)	NM	NM	NM	NM	NM	NM	NM
LILT							
LASER	NOW	LATER	X	NOW	NOW	X	X
EUNET (3)	NOW	NOW	NOW	NOW	NOW	NOW	now
DELTA (4)	NOW	LATER	later	NM	later	NOW	later
MENTOR (5)	NOW	LATER	X	NOW	NOW	now	now
IRPUD	NM	NOW	NOW	NOW	NOW	NOW	now

Notes to Table 4.4:

1 Bristol application
2 European application
3 Trans-Pennine application
4 Edinburgh application (GMSPM differences in brackets)
5 Cambridge application

Information for LILT taken from ISGLUTI Phase I Report, Table 6.9

X = no effect
now = weak simultaneous effect
NOW = strong simultaneous effect
later = weak delayed effect
LATER = strong delayed effect

NM = affected variable not modelled

2 the number and location of employment in industries catering for the local market (mainly the service industries); and

3 the resulting pattern of labour travel-to-work.

Other industries that export from the region are located by a separate procedure based on accessibility to a suitable labour supply and to other costs of location. Unemployment is not endogenously calculated. Wages respond to employees' costs of living (i.e. to changes in the costs of obtaining travel, housing and "other goods and services") so as to maintain a constant level of utility for households of each socio-economic group. Wage levels do not influence the total number of jobs in the study area other than indirectly by influencing commuting into and out of the study area. Labour is segmented by occupation to take account of local imbalances in supply.

MEPLAN (EUNET) will broadly follow the same approach as in LASER. However, as yet it has not been finalised whether unemployment will be modelled explicitly and whether the unit demand for labour by each industry will be elastic to labour costs.

DELTA: treatment of the labour market is a separate sub-model which adjusts the employment status of household members so as to fill all the jobs. The numbers of jobs by sector and socio-economic status, and of households by composition, are previously fixed by the location and other sub-models. The employment status model can therefore affect only:

- whether persons are "working" or "not working", and

- the pattern of travel to work (in those applications where this is explicit in DELTA).

Wages are exogenously specified. Changes in income due to changes in employment status affect location and housing demand in the following time period.

V&G: the mixture of labour and inputs used by producers is influenced by their respective wages or prices. A fixed supply of a single type of labour is assumed in each region, with no scope for commuting between regions. Wage rates are adjusted to equate supply and demand for labour in each region. Given the fixed supply, this means that wages are adjusted until employment matches the supply of labour.

Product markets

In EUNET, like labour in LASER, this is embedded in the central spatial input-output equilibrium calculation, which simultaneously finds the location of production (and hence of all intermediate and private final consumption) and the pattern of trade from producers to consumers. Using fixed Leontief coefficients for inter-industry transactions, all demands are met and no unused production will be generated. Through the linkage to a macro economic model reductions in transport costs lead to reductions in production costs, which in turn lead to increased economic activity in the study area. The model structure is explained in more detail in Section 6.3.

DELTA regional (under development – see later): the proposed enhancements to the regional-scale elements of DELTA will add a spatial input-output model which would in itself match the foregoing description of its EUNET equivalent, though the influences on location and trade will be different.

V&G: similar in scope to EUNET, except that the numbers of producers (each producing their own "variety" of product) by sector and region are explicit and variable, in addition to production and employment being variable. In contrast to the land-use models, imperfectly competitive markets are represented and firms can have increasing returns to scale.

Property markets
LASER: all employment and households compete for various types of floorspace; at equilibrium, all activities are located (at densities which are in equilibrium with the rents) and all floorspace is occupied. The supply of floorspace is changed over time, in a non-equilibrium process which allocates exogenously input amounts of demolition and construction to zones on the basis of expected profitability and planning policy. Floorspace built during one period is available to activities in the spatial input-output equilibrium found at the end of that period.

EUNET: is similar to LASER.

DELTA: the employment and households which are "mobile" in a particular one- or two-year period compete for various types of floorspace. Floorspace which is occupied by "non-mobile" activities is not available. At the equilibrium for a particualr period, all activities are located (at densities which are in equilibrium with the rents), but the amount of floorspace occupied may increase or decrease. Since non-mobile activities do not change their occupation of floorspace, the average density (for any one activity in any one zone) at the end of the period is not necessarily the same as the density of newly-located activity. The supply of floorspace is also changed in each period: the total amount of new floorspace of each type and its allocation to zones as based on expected profitability and planning policy. Floorspace built during one period usually becomes available to activities after a time-lag which can vary between floorspace types.

V&G: land is not mentioned explicitly, but presumably it would be treated as a factor in exactly the same way as labour, ie rents will vary, modifying the ratio of land to other inputs until all land is used.

Transport markets
Land-use models: in general these are either linked to, or have embedded within them, a representation of the transport system in which both the supply and the demand are explicitly represented. They provide an explicit description of the spatial patterns of location and of the costs of trading between pairs of locations. They contain an equilibrating process by which excess demands for the use of scarce capacity is penalised by delays, until the demand adjusts so as to be in equilibrium with the fixed supply. These congestion delays lead to increases in transport costs that ultimately feed through to the costs of production, or in the case of commuting and business travel, to labour costs. In addition to these system effects, some models include some operator responses (eg changing fares or frequencies), though generally developments in this area have been rejected in favour of keeping supply variables exogenous in order to facilitate testing the impact of different changes.

V&G: there is no representation of supply constraints in transport and a simplified representation of transport costs.

4.4 Impact of land-use change on transport

The impact of land-use change on transport is generally an immediate effect, as shown in Table 4.8. There are major differences in the way in which the impacts are applied.

In general, those land-use models which work with matrices of generalised cost or disutility are explicit spatial interaction models; they output matrices of interactions in activity or economic units, which are then converted into matrices in units of transport demand. The transport model choices are then limited to mode choice, route choice and possibly time of travel choice, as already seen in Table 4.1.

Those land-use models which work with vectors of accessibility, in contrast, generally output vectors of future land-uses by zone. These outputs are used either to generate travel or to modify existing matrices of travel demand, and destination choice is included in the associated transport model.

The GMSPM implementation of the START/DELTA combination is rather more complex for travel to work. Travel to work matrices are held both in terms of persons and of trips, and are kept consistent at each stage in forecasting. They are modified by changing destination choice in START, and in relation to changing numbers of workers and of jobs in DELTA. All other purposes of travel are adjusted in line with zonal outputs from DELTA, as described in the preceding paragraph.

4.5 Scope of different models: conclusion

By way of conclusion to this comparison of models, we return to the "actors and markets" diagram. In Figures 4.1 to 4.4 we have attempted to indicate graphically different models' coverage of decisions and of markets. The models shown are:

- DELTA/START (in their existing, urban application);
- the LASER (urban) application of MEPLAN;
- the EUNET (regional) application of MEPLAN; and
- the V&G framework.

The key to the graphics is essentially that the markets, actors and decisions represented in the model are in bold and highlighted or shaded in grey, whilst the unrepresented elements remain in plain type with dashed lines for their boxes and connections. Inevitably, some text has been necessary in order to indicate that in some cases, the same thing is represented in different ways, as identified in the discussion of markets above.

We have tried to show a little more about the representation of decisions. Those kinds of decisions which are explicitly represented as choices (whether choices of quantity, or choices between discrete alternatives) are in ***bold underlined italics***. Those which are represented as fixed functions (for example by fixed input-output coefficients, or by defining one variable as the sum of another) are in ***bold italics***, but not underlined.

The main conclusion which we draw from this way of summarising the models is that the V&G framework is not dramatically different in scope from LUTI models, except that it treats transport as just another set of products rather than by an explicit transport model which can take account of network effects. Within the overall scope of the modelling, the V&G framework is more distinct in that it treats more producer decisions as choices rather than as fixed functions. Conversely, V&G ignores many of the choices of residents, who are given more explicit attention in the LUTI models, particularly those at the urban rather than the regional level.

It seems worth noting that none of the models gives explicit attention to the process of investment, except in so far as the LUTI models consider the decisions of developers. This is a point which has been picked up in the current development of DELTA for regional application, and is discussed later (see Chapter 6). The lack of development process in V&G is associated with the static equilibrium nature of that framework. It should be kept in mind that a significant proportion of the relationships in the LUTI models operate only gradually over time, as outlined in Chapter 3.

It should also be stressed that MEPLAN and DELTA are "packages" and not "models" per se. Accordingly, these packages may be implemented in a wide variety of different ways depending on what is the primary purpose of each specific study. This means that many of the differences between their specific past implementations as discussed in this report and the V&G approach, are due more to the different focus of these past studies, rather than inherent difficulties in implementing the better features of the V&G approach. In particular most land-use models have been applied at the urban scale where passenger rather than freight traffic is the main problem. For this reason the concentration is on the markets for land, transport and service industries rather than manufacturing industries. For this reason the focus of past models, other than in regional applications of the MEPLAN model, has usually not been on product markets. This topic will be discussed in more detail in Chapter 6.

Table 4.5: **Treatment of Residents' decisions in selected models**

	MEPLAN(LASER)	**DELTA(urban)**	**MEPLAN(EUNET)**	**DELTA(regional design)**	**V&G**
RESIDENTS	*Households by zone, seg, active/inactive*	*Households and their members by zone, seg, c-o, household composition/ employment status*	*Households by zone, seg, car-ownership, active/inactive*	*Households and their members by zone, seg, c-o, household composition/ employment status*	*Either persons by zone, or only aggregate income and expenditure modelled?*
Locate	**Choose zone i, given workplace j (housing supply, utility of consumption {rents, income}, money and generalised cost of commuting from i to j)**	**Choose zone (housing supply, utility of consumption {rents,income}, accessibility, environment, area quality)**	**Choose zone i, households size, car ownership, and household seg, given workplace j and person seg (housing supply, utility of consumption {rents, income}, money and generalised cost of commuting from i to j)**	**Choose stay or migrate to other area (relative economic opportunities). Within area, choose zone (housing supply, utility of consumption {rents,income}, accessibility, environment, area quality)**	
Train	(note socio-economic status determined by demand for labour)	(note socio-economic status of residents exogenously determined by demographic trends)	(note socio-economic status determined by demand for labour)	(note socio-economic status of residents exogenously determined by demographic trends)	
Work	Determined prior to location. Unemployed households separately located	Determined by demand for labour, supply of labour, previous commuting pattern. Unemployment defined by surplus labour	Determined prior to location. Unemployed households separately located	Determined by demand for labour, supply of labour, previous commuting pattern. Unemployment defined by surplus labour. **Accessibility will influence willingness to work**	**[total wage income calculated]**
Purchase	**Consumption of floorspace elastic wrt price and income.** Fixed input-output coefficients calculate consumer final demand by product and zone	**Consumption of floorspace elastic wrt price and income.** (Other consumption implicit in utility of consumption function, but not used in product markets)	**Final demand for services and floorspace elastic wrt price and income**	**Consumption of floorspace elastic wrt price and income**	**Demands calculated by consumption function, given wage and other income**
Other activities	…generate trips	…generate trips			

bold = explicit choice process modelled (variables directly entering) {variables indirectly entering}
plain = implicit choice process; effect determined by fixed relationship to other variables.

Table 4.6: **Treatment of Producers' decisions in selected models**

	MEPLAN(LASER)	**DELTA(urban)**	**MEPLAN(EUNET)**	**DELTA(regional)**	**V&G**
PRODUCERS of goods and services	*Employment by sector and zone*	*Employment by sector and zone*	*Production by sector and zone*	*Production and employment by sector and zone*	*Firms & production by sector*
Locate	Exogenous (basic) employment distributed to zones (space, rent, transport costs). (Changes in such employment input by user)	Mobile employment located/relocated to zones (space, rent, transport costs). (Changes in employment determined by sector growth factors)		**Some investment streams will include location choice**	Firms enter/exit
Invest				**Multiple streams of investment (past or expected profitability)**	
Recruit	Fixed proportions by seg in each sector, changing over time	Proportions by seg (variable by zone), changing over time	Fixed proportions by seg in each sector, changing over time	**Fixed and variable components (production)**	Wage expenditure determined by consumption function
Purchase			Determined by fixed IO coefficients. **Zone of purchase chosen (price, transport costs)**	Determined by fixed IO coefficients. **Zone of purchase chosen (capacity, price, transport costs)**	**IO coefficients variable – determined by producers' consumption function**
Produce	Endogenous employment calculated by IO model (see residents' purchases) distributed to work zones from zones of consumption (space, rent, transport costs or generalised costs)		Demand for production driven by final demand plus intermediate demand in IO model	Demand for production driven by final demand plus intermediate demand in IO model	
Market					Price set as fixed markup on costs

bold = explicit choice process modelled (variables directly entering) {variables indirectly entering}
plain = implicit choice process; effect determined by fixed relationship to other variables.

Table 4.7: **Treatment of Developers' decisions in selected models**

	MEPLAN(LASER)	**DELTA(urban)**	**MEPLAN(EUNET)**	**DELTA(regional design)**	**V&G**
DEVELOPERS of floorspace	**4.6 Development by type and zone**	**4.7 Development by type, process (greenfield/ brownfield) and zone**	**4.8 Development by type and zone**	**4.9 Development by type, process (greenfield/ brownfield) and zone**	
How much to build	Exogenous	**Elastic wrt average profitability, subject to effects of planning policy**	Exogenous	**Elastic wrt average profitability, subject to effects of planning policy**	
Where to build	**Zone (permissible development, past rent)**	**Zone (permissible development, past rent)**	**Zone (permissible development, past and expected rent)**	**Zone (permissible development, past rent)**	

bold = explicit choice process modelled (variables directly entering) {variables indirectly entering}
plain = implicit choice process; effect determined by fixed relationship to other variables.

Note: permissible development takes into account land-use planning policy, zoning restrictions etc.

Table 4.8: **Effects of a change in land-use patterns**

Effects of a change in land-use patterns on:

	Car ownership	Work trip pattern	Other trip patterns	Modal split	Road congestion	Land-use via the transport system
DSCMOD Urban (1)	X	X	X	X	X	X
DSCMOD Regional (2)	NM	NM	NM	NM	NM	X
LILT	later	NOW	NOW	now	now	now
LASER	X	NOW	NOW	NOW	NOW	now+LATER
EUNET (3)	NOW	NOW	NOW	NOW	NOW	later
DELTA (4)	NOW	NOW	NOW	now	now	later
MENTOR (5)	NOW	NOW	NOW	NOW	NOW	later
IRPUD	later	later	later	later	later	later

Notes to Table 4.8:

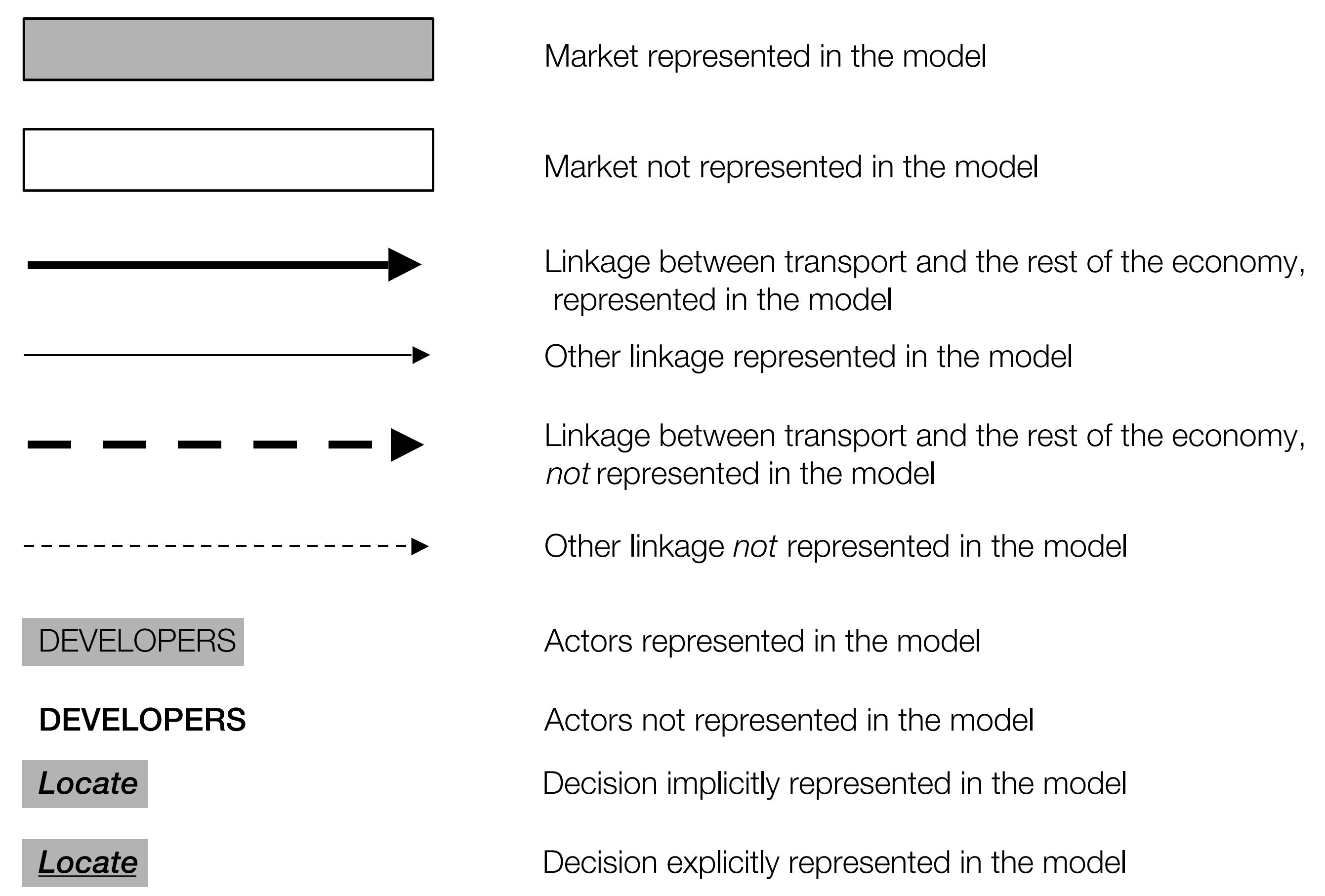
1 Bristol application
2 European application
3 Trans-Pennine application
4 Edinburgh application (GMSPM differences in brackets)
5 Cambridge application

Information for LILT taken from ISGLUTI Phase I Report, Table 6.9

X = no effect (note: for DSCMOD, this is because the results are not usually recycled into the transport model)
now = weak simultaneous effect
NOW = strong simultaneous effect
later = weak delayed effect
LATER = strong delayed effect

NM = affected variable not modelled

Key to Figures 4.1–4.4



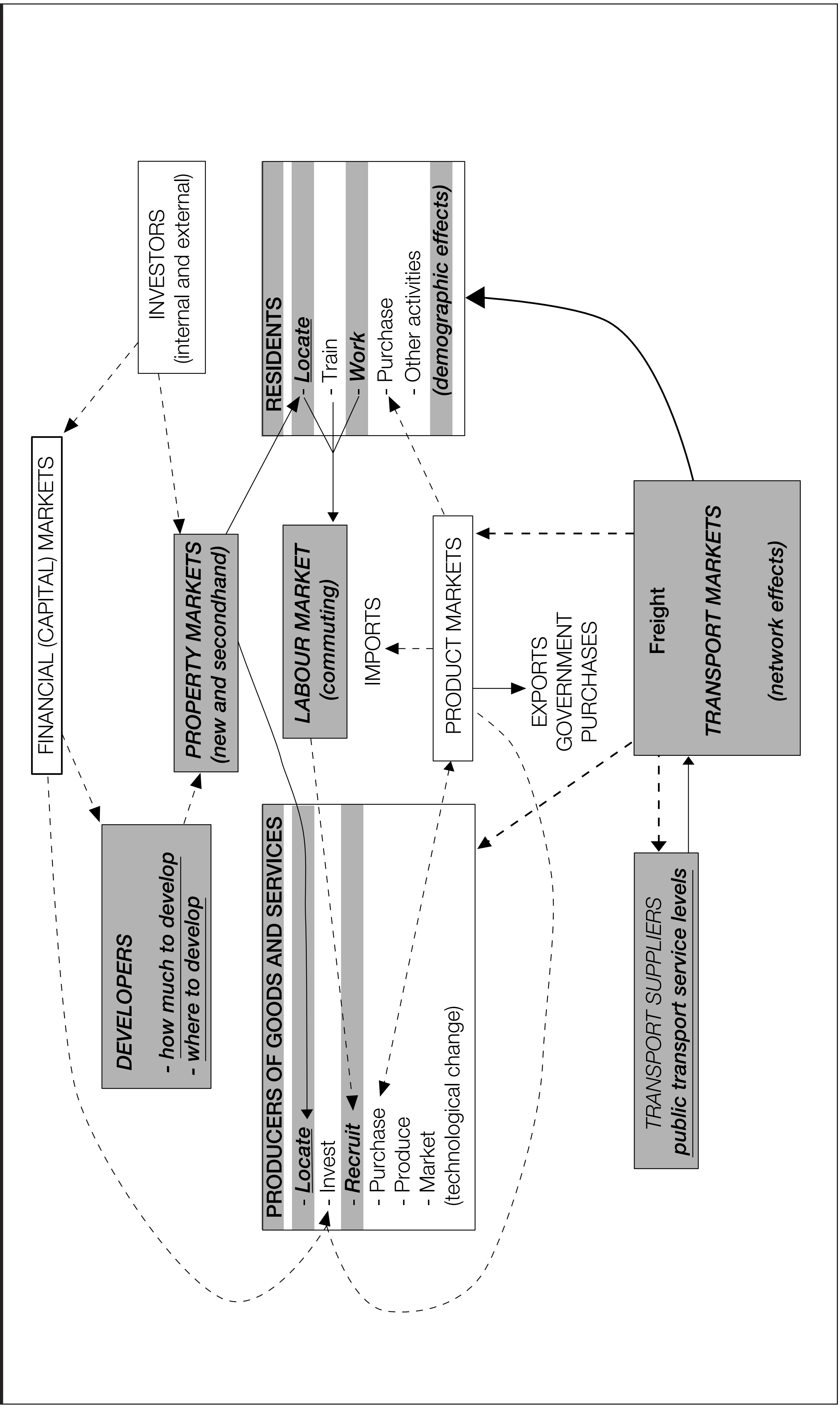


Figure 4.1: **Actors and markets in DELTA/START (urban)**

Figure 4.2: Actors and markets in MEPLAN (LASER)

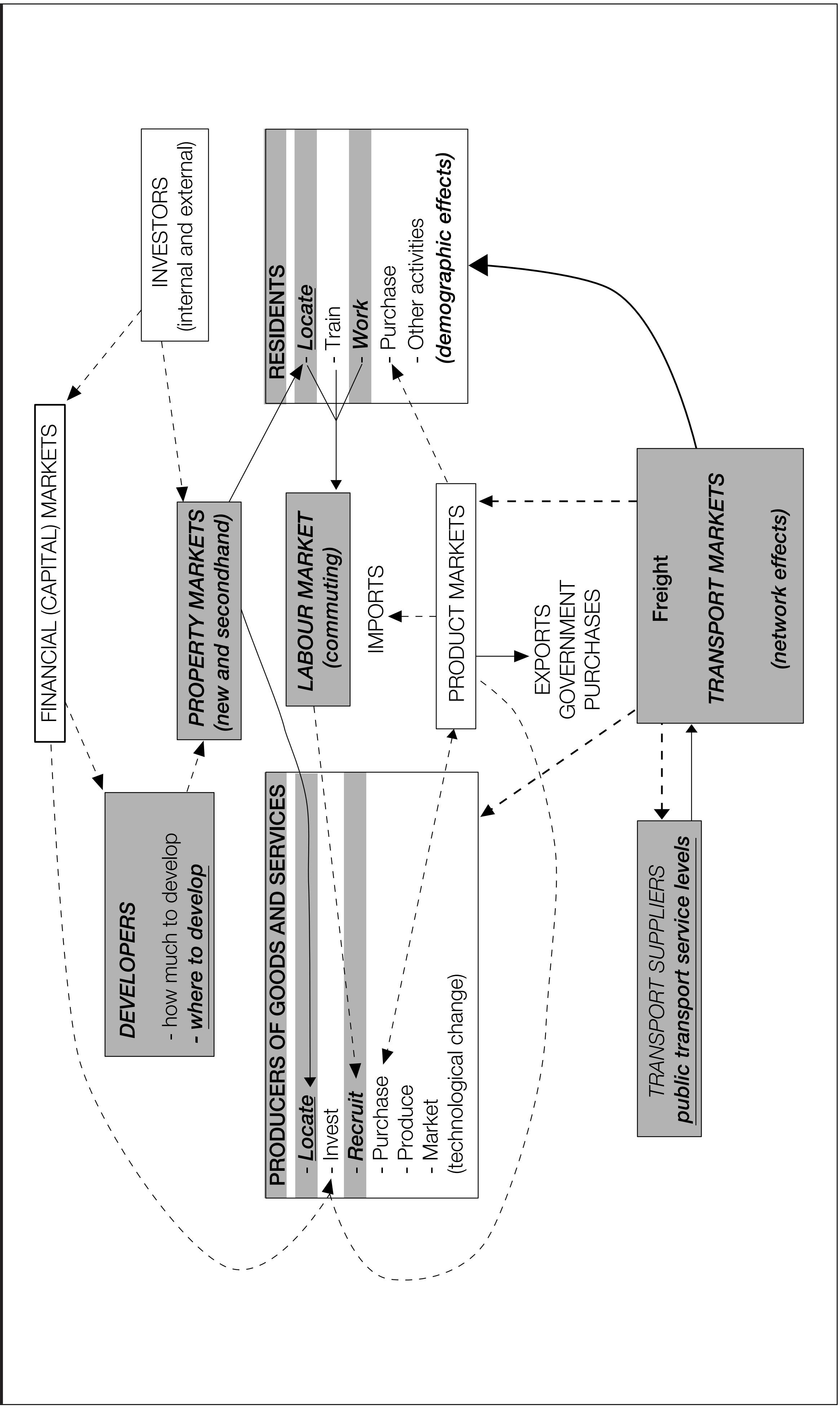
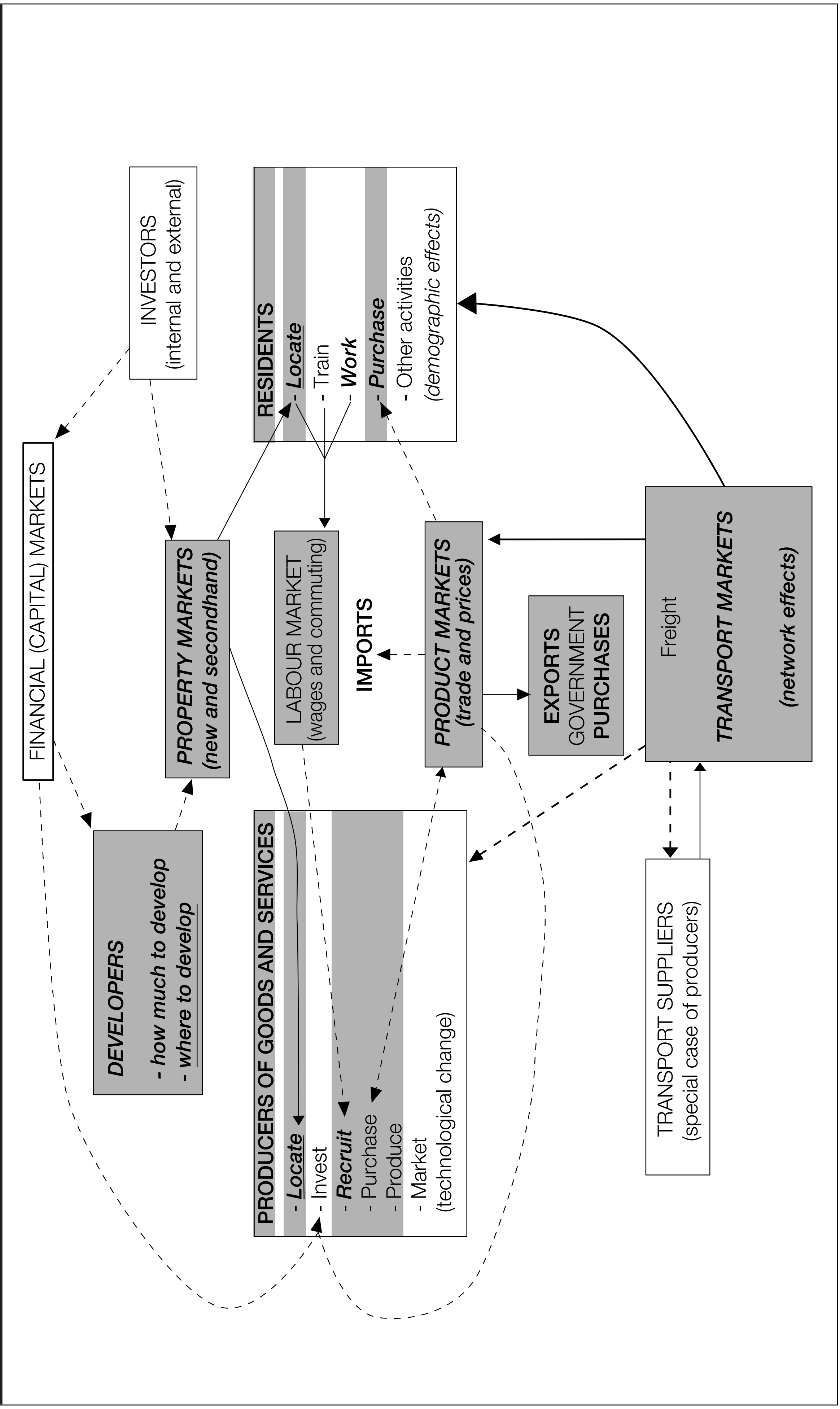


Figure 4.3: Actors and markets in MERPLAN (EUNET)



CHAPTER 5
Discussion of key issues

5.1 The two-way road argument

One of the concerns that has been raised about existing practice in assessing the impact of transport improvements is the assumption that an improvement in accessibility for a particular area will automatically be beneficial to its economy. There is concern that improving the transport links between two local economies, one of which is large and prosperous and the other of which is small and weak, may, under some conditions, lead to losses from the small-and-weak economy, despite the fact that it has gained better access to a large market. A key mechanism likely to bring this about is if the reduced transport costs make it more attractive for purchasers in the small economy to buy from suppliers in the large economy, where a wider choice of services or products is available and greater economies of scale exist, rather than buying more locally at higher prices. A common example is the way in which the growth of car ownership has contributed to the decline of village shops, the village trade going instead to town or edge-of-town retailers. The example also illustrates two relevant points:

- the change in transport may be due to factors other than infrastructure change; and
- the “two-way road” effect is perhaps more likely to apply to a particular sector than to the whole of the economy.

One can also envisage that the effect may in some cases work the other way round – that a location which is highly successful but also highly constrained (and therefore very expensive) will lose activity to a hitherto less successful and cheaper competitor if the links between the two improve. This can only occur if the previously less successful location was fundamentally disadvantaged *only* by the lack of the transport link. We suspect that this argument is used much more often than is properly justifiable.

It should be noted that there is nothing particularly surprising about the two-way road argument. It is significant here mainly because it often ignored or abused when the case for a particular scheme is being put forward.

All of the models considered in this review appear capable of predicting a negative impact in particular sectors for some of the places served by a particular change in infrastructure. The likelihood of such a result being obtained probably depends in large measure on:

- the level of zonal and sectoral disaggregation; and
- the complexity of the process for allocation or reallocation of activity to zones.

The more detailed and more complex the model, the greater the likelihood that the model would produce such an effect.

5.2 New versus displaced jobs

This is an issue which is important in the appraisal of transport expenditure when it is intended to have wider economic benefits. Decision-makers will be concerned, when they spend money to create jobs in a particular location, to understand the extent to which these are "additional" jobs and not just jobs moved from elsewhere within their jurisdiction. Alternatively, if the objective is to create new jobs in an area of high unemployment, the concern will probably be to ensure that these jobs are "moved" from areas of very low unemployment, rather than from other depressed areas. In general, therefore, any claim that a transport scheme will create jobs generates a requirement for information as to where, if anywhere, those jobs have come from.

The issue seems to be based on the premise that jobs, like people, are identifiable, and that if they are not in one place then they must be in another. Under some circumstances, this seems reasonable – for example, when several locations are competing for the attention of a major inward investor whose declared intention is to set up a major new establishment. In many other cases, the distinction between "new" and "displaced" jobs seems wholly artificial. For example, jobs in a wholly new start-up firm would by definition by counted as "new", but the firm may simply compete with other existing firms and cause them to reduce their workforces.

None of the models which we have been able to review in detail actually works in terms of firms[6]. They all model employees by sector and zone, and therefore permit simply a comparison of numbers of employees in each zone at each modelled point in time. There are some technical differences between the models in terms of whether they represent closed or open systems. However, there seems to be a growing level of agreement (certainly between ME&P and DSC) that the modelled area should always be larger than the economy of interest, which means that the economy of interest adjacent to a scheme will effectively be treated as an open system.

The implication is that, if a model is representative of good practice:

1. it will be able to show whether a transport change within the area of interest has a net positive effect on the economy of that area, rather than just redistributing jobs within that area; but

2. it will not strictly speaking distinguish between "new" and "displaced" jobs, except in some special cases, though it may be possible to interpret the results in such a way.

The EUNET regional economic model has options to allow the developmental impacts of transport improvements to feed through to employment gains for the study area as a whole, through linking to a macro economic model. This is discussed in more detail in Annex C.

6 MUSSA definitely works in terms of a disaggregate model of "firms", but so far as we are aware it is limited to representing their location, and cannot reproduce any other responses to changing circumstances. The way in which MUSSA works would seem to leave relatively little difference between modelling the location of firms and modelling the location of employment. URBANISM is similar to MUSSA.

5.3 Unlocking sites

The possibility that transport improvements can "unlock" sites with potential for employment-generating development can be split into three different effects. Note that the distinction between the first two depends on the scale of analysis rather than upon a difference between the processes:

1. improved accessibility makes development appear more profitable and encourages developers to develop more land in zones where development already exists;

2. improved accessibility makes development appear more profitable and encourages developers to develop more land in zones where no development of that type previously exists; and

3. improved access makes development of particular sites acceptable where previously it was unacceptable on traffic and amenity grounds.

Most of the dynamic models considered in this Report contain at least some representation of:

1. the market for additional construction where land is available in zones which already contain similar development; and of

2. the changes in rent that result from the resulting increased supply of each type of floorspace.

These mechanisms are outlined in the Annexes for the various models. It is not always clear that they operate in a form that would enable the appraisal of resulting costs and benefits to be carried out straightforwardly. The representation of this process is clearly one case in which a land-use model provides added-value to a transport model.

These mechanisms do not generally work well when the zone contains no existing floorspace of a particular type. Although it is quite common to apply the models so as to represent major developments in hitherto empty zones, this requires some degree of "seeding" of the relevant variables to reflect existing assumptions or expectations. Such tests mean that typically the model is assessing the impact of the expected development, rather than assessing whether or not it will occur.

The models considered in this review are essentially unsuitable for considering the degree to which road or other transport improvements can "unlock" the development potential of specific sites, where there is little or no current activity. This is because all of the models rely to some extent on the previous characteristics of each zone to predict how that zone will be affected by transport changes. Other work on different kinds of models is attempting to overcome these limitations and may be able to assess the unlocking effects of transport (and other) changes. This requires a very detailed representation, probably by microsimulation, of the processes of development and take-up for each site within an area. Some research on this kind of modelling has been done (see for example Landis, (1994)), but we do not have sufficiently detailed information to comment on how successful it has been.

5.4 Measuring user benefits in land-use/transport models

In Chapter 4 we considered the impacts that result from different types of change in the selected models. This current section focuses on how those *impacts* that are measured by a model can be converted into appropriate measures of *benefits*.

In order to measure the benefits arising from a land-use or transport policy initiative, a land-use/transport model should ideally satisfy the following broad requirements:

1. the transport model's estimates of the travel demand patterns should be a consistent outcome of the interplay between all of the major behavioural travel responses to changes in the costs and the characteristics of the supply of transport;

2. the land-use model's estimates of the spatial location of the activities which are creating these travel patterns, should likewise be based on behavioural representation of the different actors involved; and

3. a suitable procedure should exist which consistently measures the user benefits without double counting.

This set of requirements represents the ideal towards which models should aim. However, it also implies a level of complexity and of data resources that make the ideal unlikely to be achieved, other than in expensive sophisticated studies which are analysing transport initiatives large enough to have significant impacts on all of the markets identified above.

What then can be learned from more partial approaches? How can the best value be achieved in smaller scale studies which are analysing initiatives that create only smaller scale, less all-encompassing impacts? To address these general issues, a number of more specific questions arise when selecting an appropriate model for a study:

1. how can the assessment approach guarantee that no major source of user benefits is either missed out or double counted within the model?; and

2. which user benefits should be measured within the transport model component and which within the land-use model component?

These two questions are explored in more detail in subsequent sections.

CONSISTENT AND COMPLETE SETS OF USER BENEFITS

5.4.1 To guarantee that all of the major sources of user benefits can be included accurately and consistently in an assessment procedure, the following modelling requirements are generated for each of the main behavioural responses to policy initiatives:

1. The model itself should contain an appropriate representation of this behavioural response – the range of relevant land-use and transport behavioural responses included within existing models has already been presented in Chapter 4;

2 The model should adopt a level of segmentation sufficient to assign the major observed differences in behavioural responsiveness into groups of homogeneous actors – the modelled response of a single "average" individual is frequently not the same as the population weighted average of the modelled responses of a set of homogeneous groups within a population. Empirical experience suggests that the responses may not even have the same sign in some cases so that insufficiently segmented models may prove quite misleading. The levels of segmentation typically adopted in past UK model implementations are presented in Volume II and the tendency would appear to be towards increasing segmentation;

3 The strength/elasticity of each behavioural response in the model should be calibrated so as to match the real world pattern of behaviour, both when the response is viewed in isolation from, and in combination with, other behavioural responses;

4 The model should be able to respond to both monetary (e.g. price increases) and non-monetary (e.g. time savings, quality improvements) utility effects and furthermore to take account of the relative differences of those with different levels of disposable incomes, in their responsiveness to monetary costs;

5 The model should link together the full set of other behavioural responses in a manner that replicates their real world interrelatedness. In the case of an improvement to a link of the network this should feed consistently through the full set of behavioural responses. In most models, this would have an immediate effect on route choice, and a chain of consequences with various time lags through other transport effects to choice of employment and residential location, and eventually to the location of new floorspace development. The way in which the sequence of effects works varies between model approaches, but attention should be given to the ways in which both monetary and non-monetary impacts should be passed from actor to actor;

6 The behavioural responses should be represented in the model in an incremental form starting from the most appropriate available information about the base situation, excluding transitory effects. More recent transport models such as START (Bates et al, 1991) and APRIL (Williams & Bates, 1993) have developed techniques suitable for incremental modelling. The START model uses a conventional explicit incremental model, whereas the APRIL road pricing transport model and the MENTOR land-use model use an implicit incremental approach based on residual disutilities (Williams & Beardwood, 1993). There is scope for debate about what exactly constitutes the most appropriate basis for an incremental model. This is particularly important when modelling the pattern of freight flows. An observed base matrix will reflect inter alia (a) the inherent heterogeneity in goods and in the firms that make them, even in highly segmented models; (b) historical or other long-term influences on the pattern of trade, and (c) short-term influences such as deliveries to major construction projects. The significance of each of these for future flows needs to be considered.

None of the models reviewed in this study is ideal in relation to this challenging set of criteria for a complete set of major behavioural responses, even at the existing state-of-the-art in modelling. In most cases, this is due to the resource limits in the studies for which the models were developed. The models are however sufficiently advanced that it is appropriate to give further attention to the issues of where and how to assess user benefits, working towards the question of how the scale of benefits measured within a comprehensive model would differ from those measured in a transport-only model.

WHERE TO ASSESS USER BENEFITS

5.4.2 The modelling requirements 1, 2 and 3 listed in the previous section could, in principle, be covered by many of the available packages, albeit using somewhat different approaches. However, there is a significant difference in structure between groups of the models in relation to how the land-use and transport systems are connected. These influence the ways in which user benefits may be assessed. Accordingly this topic is discussed in more depth in order to highlight their differences that relate to the modelling requirements 4 to 6 of the previous section. This will also provide the background to the issues of where in models should user benefits be assessed, and how to avoid double counting of these benefits.

As previously noted in Chapter 4, one group of models determines the changes in the zonal pattern of location of households and employment based on measures of *zonal accessibilities*. These zonal accessibilities are derived by aggregating across zones the generalised costs of transport that are output by zone pair from the transport model. This approach is used in the entropy based models such as LILT, the static models such as DSCMOD, the microsimulation model of IRPUD, the spatial-economic model MUSSA and in activity based models such as DELTA and URBANSIM. In all of these models the estimation of the O-D trip distribution matrices is then carried out separately in a transport model, based on the spatial pattern of land-uses generated in the land-use model. This approach to modelling will be termed "linked land-use and transport models" (LLUTM).

The other group of models determines the changes in the zonal pattern of location of households and employment based directly on the *O-D zone pair matrices* of generalised costs output from the transport model. This approach is used in the spatial-economic approach adopted in the METROSIM, TRANUS, MEPLAN and MENTOR packages. In the models derived from these packages the estimation of the O-D trip distribution matrices is an integral part of the land-use model procedure to locate households and employment. The transport model proper then starts with the modal split/time period choice stage and does not contain a repeat of the trip distribution model. This approach to modelling will be termed "integrated land-use and transport models", or ILUTM.

It is important to note that the issue of the nature of the linkage between the land-use and transport models is *not* the same issue as to whether the land-use model contained in one package can be connected to a transport model from a different package. For example, the IRPUD model is a linked model system in these terms, but is a single purpose-written piece of software containing its own transport model. In contrast, MENTOR is integrated in its approach, but is designed to operate with other transport modelling packages such as SATURN.

MEASURING BENEFITS IN INTEGRATED LAND-USE/TRANSPORT MODELS

5.4.3 In the ILUTMs there is experience in the measurement of benefits related to land-use changes, either caused by transport or land-use policy initiatives. These models are designed to try to provide a transparent mechanism through which changes in the costs and characteristics of transport feed through in a spatially detailed, segmented fashion to influence the location choices in the land-use model. This mechanism uses a hierarchical logit choice structure at each stage of the model. Huw Williams (1977) demonstrated the importance of the use of the log-sum formulation to calculate a *composite* travel disutility as the method for transmitting information on generalised costs from a lower level of decision making to higher up the hierarchy of choices. Using this mechanism he showed that user benefits could successfully be measured at the top of the decision hierarchy in a manner that is fully consistent with the underlying behavioural mechanisms embedded in the utility functions used in the different parts of the model.

Within the ILUTMs the decisions by individuals on where to live, given the location of their workplace, and on where to travel to shop or to attend school, given their place of residence, are estimated using a logit model based in part on the travel utility to each competing destination zone. This travel disutility will have been composited across modes and time of day, etc as part of the transport model. This ensures that the generalised costs of travel will influence location patterns in a form that is behaviourally consistent with their influence on the estimated pattern of trip making in accordance with the Huw Williams' formulation.

Moreover, the actual monetary costs of travel by members of a household of a given type within each residence zone can be accumulated precisely, in parallel with the composite disutility of location for that household. This ensures that when the model is run into the future, even if the monetary costs of travel do not change in real terms, the patterns of travel will still tend to change in response to the reduction of the travel deterrence of monetary costs that will result from the expected real growth in incomes for each type of individual and household. This ensures that the models will contain an income elasticity which will endogenously give rise to increases in average lengths of trips for each trip purpose. Since increase in trip lengths, rather than in numbers of trips per person, have been the main source of the observed increases in overall travel demand, this mechanism is crucial to the representation to the real world economic behaviour.

Some research has previously been carried out by ME&P(1994) in a DOT/HM Treasury sponsored project on economic evaluation methodologies for the LASER model. This concluded that the principle of compensating variation appears to be the most promising approach to measure benefits to households. The method of *compensating variation* is formalised by calculating the amounts which could be taken away from agents by leaving them no worse or no better off after the alternative has been introduced, than if it had not been introduced. The calculations are carried out separately for each homogenous group of agents. Then these numbers can either be summed together arithmetically, or preferably would be weighted to take account of social preferences to produce an overall total measure of social welfare. It has a further advantage in that it avoids the errors inherent in the use of the traditional rule-of-a-half approximate measure that have been highlighted by Huw Williams (1977) and others.

At the time of this research in 1994, the pure money component of the measure of compensating variation was fully operational within MEPLAN so that it was possible to trace all changes in money flows between agents and ensure that there were no unaccounted for leakages or receipts. However, the non-cash changes in welfare (e.g. travel time or quality, amenity value of a zone, etc.) could not be traced fully through the system. As part of the research into the MENTOR package, this has since been rectified and a new circuit of utility (non-cash) flows is now implemented to run in parallel with the original circuit of money flows in both the MEPLAN and MENTOR packages. However, as yet the development of suitable production functions for firms to complement the utility maintaining consumption functions of households, has not been addressed in MEPLAN model applications. There is further discussion in Chapter 6 on the ways in which elastic production functions that take account of increases in productivity or competitiveness could be used to represent product markets in the EUNET model, in place of the fixed Leontief coefficients that are in current use.

The discussion above does not seek to imply that the full set of outstanding issues related to the assessment of land-use and transport responses has been resolved in the ILUTMs. It has not. The current situation is that the ILUTMs provide a clear structure within which outstanding assessment issues can be explored both empirically and theoretically. However, more practical experience in their use is needed before these methods can be used unquestioningly, and some research issues are still outstanding, including:

- testing in practice the method of compensating variation and ensuring that all of the operational details in enabling it to work fully for all types of policy initiatives in a full scale model have been resolved;

- how to link the models of floorspace development and of relocation of industries (especially those catering mainly to external markets) into the assessment system?; and

- how to make the assessment fully operational when the land-use and transport models are both implemented in an incremental rather than in a synthetic model form.

MEASURING BENEFITS IN LINKED LAND-USE/TRANSPORT MODELS

5.4.4 By definition, LLUTMs incorporate a distinct and separable transport model, and the obvious approach[7] to the measurement of user benefits would be to start by calculating a consumers surplus measure based on the outputs from transport model. To this, one would then add a calculation of the additional benefits based upon the responses of the land-use model.

A much more promising approach has however been developed by Francisco Martínez and colleagues in Chile. This relies on the close relationship or identity between measures of accessibility and measures of transport user benefit. If the LLUTM uses proper measures of transport user benefit to describe the influences of transport upon land-use, it is possible to carry out a comprehensive evaluation within the land-use model. The mathematics of this, and the results of a practical test using the MUSSA-ESTRAUS LLUTM, are shown in Martínez and Araya (1998). Amongst other points of interest, this paper argues that the "conventional" economists' claim that a fully-specified measure of transport user benefit will capture all land-use user benefits is true only under an unrealistically restrictive set of assumptions. The difference between transport user benefit and land-use user benefit is shown both mathematically and by means of model results. Moreover, there appears[8] to be an argument for claiming that the measurement of transport benefits from within the land-use model is (a) the correct approach to the assessment of benefits in the longer term, and (b) likely in most cases to give smaller benefits from transport improvements than a more conventional assessment within the transport model.

7 This approach was suggested in the Interim Report.

8 Note that the Martínez and Araya paper was distributed at the World Conference on Transport Research in July 1998; some further material from the same authors has been received more recently. We cannot claim to have absorbed all its implications yet.

This general approach would seem applicable to other LLUTMs such as DELTA and URBANSIM. For use in DELTA, certainly, a number of major questions will need to be resolved, notably how to apply the approach within a non-equilibrium model.

WHERE TO MEASURE BENEFITS?

5.4.5 The answer to this question is that benefits should be measured in the land-use model, whether the model is integrated with or linked to the transport model (in the specific senses used here). The main reason is that reductions in the generalised costs of transport generate a chain of adjustments in the land, labour, property and product markets. These allow firms to produce more efficiently and/or allow consumers to increase their welfare. Consequently, the assessment system should measure the extent to which these adjustments amplify the direct benefits arising from transport cost reductions.
The magnitude of these knock-on adjustments may well be substantial. The evidence of behaviour over the 22 years from 1974 suggests strongly that the major response to the reductions in the unit costs of transport is to travel further, rather than simply to avail of generalised cost savings without changing transport patterns. This is equally true for both passenger and freight transport. In Great Britain over this 22 year period there have been relatively low rates of growth of 10% in overall passenger trip rates per head, and of 12% in the total number of tonnes of freight moved on roads. In contrast there have been substantially larger increases of 31% in the average trip lengths for passengers and of 69% in the total tonne-kilometres for freight moved by road.

These trends strongly suggest that the benefits from reductions in unit transport costs do not stay within the transport sector, but lead instead to changes in patterns of industrial location and distribution, which presumably facilitate more cost-effective forms of production and marketing. A land-use/regional economic model is needed in order to model these behavioural responses, and thus to enable their effects to be included in a fully specified CBA.

Further research is needed to measure the extent to which either:

- consumers and firms do change their behaviour to adjust to changed transport costs, but these behavioural adjustments do not lead to further significant welfare or productivity gains for them (if this were true then perhaps the benefits measured within the transport model alone would suffice); or alternatively,

- the adjustments in behaviour are indicative that transport acts as a catalyst to enable other benefits to be achieved, and that the magnitude of the longer term changes in travel behaviour in response to changes in transport costs are an indicator of the existence of significant productivity gains for firms and of welfare gains for consumers. In this case the benefits must certainly be measured in the land-use model.

This empirical analysis is not inconsistent with the V&G framework which outlines theoretically how to capture the benefits of increased productivity within the product markets and for consumers. The benefits to consumers from transport led increases in choice/productivity in the service and retail industries, and in property markets are already measured approximately in operational land-use models such as LASER. The way in which the V&G approach to measuring benefits could be implemented more fully in an operational model is described in Chapter 6.

In the case of the ILUTMs, it has been shown the method of compensating variation is more comprehensive than approaches based on the rule-of-a-half, and can, in principle, accurately address all forms of policy initiative. Accordingly, it would be the preferred approach, subject to satisfactory completion of the further research tasks listed above. It should then provide a complete measure of benefits of any mixture of land-use and transport policy initiatives without double counting.
For LLUTMs, it would appear that current research is coming to very similar conclusions, though again, much remains to be done.

There appears to be a correlation in both ILUTMs and LLUTMs between the advancement of user benefit calculations and the use of equilibrium assumptions within the model proper. Further research on the calculation of benefits in non-equilibrium conditions would seem to be appropriate, and relevant to both groups of models.

CHAPTER 6

Relationship to the Venables and Gasiorek approach

6.1 Introduction

The Terms of Reference from SACTRA of this Review of Land-Use/Transport Interaction Models requested clarification of the extent to which the theoretical bases of the models reviewed are consistent with, or in conflict with the Venables and Gasiorek (V&G) approach. Their approach demonstrates that there are potential welfare benefits due to imperfect competition that currently may be missed out in conventional CBA assessments of transport initiatives. There appears to be general agreement that their approach provides theoretical insights of considerable interest. These come about because they treat a specific market, that for products, in considerably more theoretical detail than that which has been the norm in operational land-use transport models.

What as yet is less settled is the extent to which these insights can be introduced into operational use to analyse either specific schemes or more general transport policies, rather than remaining primarily of use in more abstract theoretical analysis. In the rest of this section we discuss how existing operational models could be extended to take these insights on board to the maximum extent feasible. We investigate the main extensions that would be needed to adapt two operational packages (MEPLAN and DELTA) to represent the markets within them in a way that covers the issues raised by V&G, as we believe that this is the most transparent way to clarify their consistency with the V&G approach. This investigation distinguishes:

(a) those theoretical structures that are already well covered in existing or proposed applications of the package;

(b) those theoretical structures that do not lend themselves to easy implementation within the package; and

(c) other aspects of each package that might potentially enhance the theoretical approach outlined by V&G.

These particular packages were selected because they are two of the packages in which the representation of markets is currently furthest developed and so will provide the clearest insights into the current state of the art in operational land-use/transport modelling with respect to the V&G approach.

Section 6.2 provides some background on the differences in the purposes for which the two strands of modelling were originally designed. Section 6.3 considers the developments that could potentially be carried out using MEPLAN. Section 6.4 considers the same issues in relation to DELTA. In Section 6.5 some overall conclusions are drawn on the most productive areas for further development.

6.2 Background on the design of the models

Before embarking upon any comparison between the characteristics of the land-use/transport interaction models and the characteristics of the V&G framework, it is instructive to describe the background to the design underlying each approach.

The purpose of the V&G framework is to investigate "ways in which market imperfections can be incorporated into the appraisal of road improvement projects". In essence it endeavours to extend the theoretical representation of markets for products beyond the traditional assumptions of perfect competition by introducing insights and techniques from the "new economic geography" as developed by Krugman and others. It then provides a simple computable equilibrium model of regional location and trade that illustrates the nature of the changes in the estimates of benefits that may arise as a result of these market imperfections. The primary focus of both the paper and the model is theoretical, with the data fed into the model being hypothetical examples made up to illustrate the approach, rather than being chosen to describe any specific real world application.

In contrast, the MEPLAN and DELTA packages have been developed for operational use to analyse a range of land-use and transport policies to be applied to a specific study area. In any specific application the primary focus of these models is operational more than theoretical. Typically they try to provide a comprehensive representation of **all** of the main mechanisms that drive the demand for location and transport in the particular study area in which they are being applied. This plus the need for observed data on which to calibrate realistically each of the mechanisms within the model, and the need to ensure that the model will provide detailed spatial results within a finite computer run time, all act as constraints on the level of theoretical detail in which any one specific aspect of market behaviour is actually represented in a particular application of the package to a specific study area.

Clearly, the ideal approach would be to harness the theoretical insights of the V&G approach within the operational framework provided by a specific application of one of the packages. This would ensure that the resulting numerical measurements of the excess benefits over and above the traditional CBA approach took direct account of:

(a) the actual transport costs and conditions in the study area, faced by both passengers and freight for the range of movements that they make – this should include consideration of competition between modes, economies of scale for transport enterprises, congestion effects, etc;

(b) the length of time over which the changes in trade and location patterns would occur – an incremental approach with lagged responses, rather than a timeless equilibrium approach; and

(c) the impacts on the labour, property, financial and transport markets as well as the product markets.

This ideal in practice is still some way from being completely feasible, but nonetheless significant progress can already be achieved. The review of the two packages in the next two sections will show which are the aspects of the V&G approach that do not fit easily within the existing packages, and which are their current areas of strength.

6.3 Implementing the V&G approach within MEPLAN[9]

INTRODUCTION

6.3.1 The MEPLAN package contains procedures to represent the majority of the features that are included in the model specified in Appendix 2 of V&G (1999). These are discussed in more detail below. Many of these features are already included in the EUNET integrated regional economic and transport model currently being applied to the Trans-Pennine Corridor region. That application is described in more detail in the Annex C of this report. Other features have been implemented in previous urban/metropolitan MEPLAN applications, such as LASER also described in Annex C, but for simplicity will not be within the EUNET application.

Taking this EUNET application as a foundation, this section describes below the way in which (after some further development and recalibration) a demonstration model could be implemented using the MEPLAN package which makes operational the majority of the features of the V&G approach, though not always using identical mechanisms. We also identify specific topics of research that would be required in order to provide a more complete representation of the impacts of imperfect competition within this demonstration model, and identify those aspects of the V&G approach that are not easily introduced into the existing MEPLAN framework.

This demonstration model could then be used to explore in a real world context, based on actual observed data, the magnitude of the extra benefits related to imperfect competition that would arise from specific traffic schemes and transport policies. The cost benefit module of MEPLAN could be used to carry out the CBA in various ways in order to explore in practice the scale of the missing benefits that arise when carrying out the CBA at different levels of simplification.

In order to provide a formal correspondence with the V&G model, the form of the demonstration model is described in sub-sections 6.3.2 to 6.3.4 in terms of the numbered equations that are listed in V&G's Appendix 2. The reader who is not interested in the precise economic details of this correspondence can skip to 6.3.5 where the main findings are summarised in a less formal fashion.

ISSUES THAT ARE ALREADY WELL COVERED IN EXISTING APPLICATIONS OF THE MEPLAN PACKAGE

6.3.2 (i) EUNET currently distinguishes 40 industrial sectors (including both manufacturing and services) and 92 internal and 35 external zones. The EUNET study area covers the whole country, although zones distant from the main area of interest are very large. It would be beneficial to aggregate the zones considerably in order to free

9 This section is essentially the work of ME&P. DSC do not necessarily disagree with the suggestions as to how the V&G concepts might be brought into the MEPLAN framework, but are not in a position to comment on their feasibility.

resources to improve the detail of other aspects of the model. Aggregating the industries is less beneficial since maintaining a detailed segmentation enables the model to maintain some of the real world heterogeneity and complexity of the range of inputs and outputs that are transported between firms. The model includes both imports and exports to/from the external zones outside the UK.

(ii) The EUNET regional economic model (REM) component maintains a complete input-output structure and so handles fully all forward and backward linkages between industries. It contains the V&G equations [8] and [20] which are used to represent the relationship between final consumer demand, intermediate demand and the total level of production in each zone.

(iii) The EUNET REM includes not only the conventional industrial and service sectors of the economy, but also it endogenises labour and households in a social accounting matrix (SAM) framework. In particular, the travel costs of labour from their zone of residence to their workplace are included as part of the costs of labour and so enter into the endogenous wage determination process along with housing rents and other household consumption costs. This includes the V&G equations [18] which defines the consumer's budget constraint, and [19] which defines the consumer's expenditure function, though traditionally MEPLAN models have used a Stone-Geary[10] form, rather than the Cobb-Douglas functional form that is used by V&G, for the consumer's utility function.

ISSUES NOT CURRENTLY IMPLEMENTED WITHIN APPLICATIONS OF THE PACKAGE

6.3.3 (i) Current applications of the REM do not have a sophisticated representation of the supply side of industries. In particular, increasing returns to scale for individual firms are not included explicitly, since the REM does not operate at the level of the individual firm within an industry within a zone. Consequently, the REM does not have any equivalent to the V&G equation [16] which defines a Nash equilibrium in prices among competing suppliers, and which is used to calculate the long run number of firms in each industry/zone combination. To provide a realistic treatment of local economies of scale within the demonstration model would ideally require the introduction of a profile of the observed current spread of sizes of firms within each industry/zone combination. This would be a substantial task to make operational in any comprehensive model, both because of its requirements for data, and because of the impact it would have on the resources needed subsequently to run the model.

10 The Stone-Geary utility function is defined as

$$u = \prod_i (c_i - \beta_i)^{\omega_i}$$

where c_i is the quantity of the input *i* that is consumed and ω_i s its share of the consumer's discretionary expenditure. The parameter β_i denotes the subsistence level consumption of the input *i*. Its expenditure system is a linear function of income *y* and prices r_i, giving

$$c_i r_i = \beta_i r_i + \omega_i \sum_i (y - \beta_i r_i)$$

In the case where β_i is set to zero throughout, this system defaults back to the Cobb-Douglas form used by V&G, and the expenditure shares then are independent of the level of income.

(ii) An alternative approach which could be introduced into the demonstration model would be to adopt an aggregate zonal representation of economies of scale using V&G's equations [12] and [15], rather than working at the level of the firm. This equation sets the prices for monopolistically competitive industries to have a constant mark up over marginal cost. This equation [15] could be introduced for the sub set of monopolistic industries, in place of the V&G equation [17] currently in use in EUNET. This latter equation would then continue to be used only for the residual sub set of fully competitive industries, and would set prices based on constant rather than increasing returns to scale.

(iii)A review of existing empirical economic research would be required initially in order to identify which types of industries in which locations were in a sufficiently monopolistic position to be able to maintain significant permanent price mark ups and then to estimate the expected magnitude of these mark ups. This review should provide well founded information that could be used to replace the hypothetical parameter values that have been adopted in the V&G Appendix 3 and which would ensure that the measures of benefit that are ultimately estimated will have realistic magnitudes.

(iv) For inter-industry transactions the EUNET model uses fixed Leontief technical coefficients rather than the Cobb-Douglas technology adopted in equation [13] by V&G. The unit consumption rates of the primary factors labour and capital are currently set to be fixed within an industry, while those for transport and floorspace/land are currently set to be elastic to price. The MEPLAN package would allow switching from Leontief to Cobb-Douglas functions for inter-industry and primary factor consumption if required.

(v) Our expectation is that the changes discussed in this section should not significantly decrease the stability in the MEPLAN demonstration model results. However, empirical testing would be required to confirm this expectation. Because the transport costs between zone pairs are accurately measured and are not tiny, and because the location of labour and of industries is constrained in any one time period by a slowly changing total stock of household dwellings and of commercial floorspace, the fluidity of the model is endogenously damped down to a level that should match the real world rate of evolution. This expectation is subject to the proviso that the economies of scale are realistic, and that due account is taken of the impact of variety of goods and of heterogeneity of firms on the likely magnitude of economies of scale achievable in practice in the real world.

POTENTIAL IMPROVEMENTS TO THE APPROACH OUTLINED BY V&G

6.3.4 (i) The EUNET REM is linked to a fully operational, freight and passenger, multi-modal (road, rail, air and shipping), network based, transport model. It measures precisely the real transport costs to intermediate or final demand from the zone in which each input good is produced. It includes congestion effects and passenger travel time costs, as well as conventional freight vehicle operating costs. It operates at a level of segmentation that enables differences in costs between broad categories of goods, of persons and of trip purposes to be distinguished explicitly. In this way it provides a detailed representation of the operation of the set of markets for transport. In the EUNET model the crude transport costs in the V&G equations [12] and [14] are replaced by precisely measured estimates of the generalised transport costs by mode facing a consumer in a specific zone for each type of input good shipped from each of the production zones from which he purchases goods.

(ii) The distribution of trade between production and consumption in the EUNET REM is based on discrete choice models which act by endeavouring to minimise costs, while taking account of the uncertainty and heterogeneity that is inherent in the real world. These use a logit discrete choice structure to represent both the competition between producers in different locations, and the diversity of products within an industry. In particular, the log-sum composite cost form pioneered by Williams (1977) is used in place of the constant elasticity of substitution (CES) sub-utility function that V&G adopt in equations [9] and [10], to provide a price index that represents the diversity of products supplied from a specific industry to a single location for consumption. McFadden (1978) has shown that the CES and multi-level logit forms can each be considered as simplifications of the same General Extreme Value family of choice models.

(iii) The logit discrete choice form provides a widely tested, convenient representation of trade patterns that can be calibrated to match closely to real world transport flows. Accordingly it is used in place of the V&G equation [11]. The Armington assumptions of product differentiation by source, discussed by V&G, have been introduced into MEPLAN discrete choice models of trade through use of the residual disutility approach described in Williams and Beardwood (1993).

(iv) Along with the transport and product markets that have already been discussed above, the EUNET model also explicitly represents the markets for the factors of production, labour and property. For property, separate competition is included for the markets for dwellings, offices, retail and industrial floorspace/land. The level of rent per unit of floorspace and the density of occupation are determined exogenously in each zone so as to equilibrate demand with supply. Factor market clearing equations similar to V&G's equations [21] and [22] are used.

(v) It is envisaged that the companion incremental models of the process of construction and demolition of floorspace by type through time will be relatively simple, but this aspect of the EUNET model as well as the nature of the representation of the market for the land on which to build, have not been finalised as yet.

(vi) To represent the labour market, the EUNET model segments the labour force into four broad occupational groups. This enables the differences in the demand for skills by different industries to be distinguished, as well as the resulting differences in average trip lengths of commuting, in household income levels and in the price elasticities of consumption that ensue. Incomes are determined endogenously. The pool of labour in each occupational group is determined by the number of persons who are economically active within the households resident in each zone of the model. If circumstances or planning policies ensure that sufficient dwellings are not available in the locality of large concentrations of demand for labour, the incomes paid in such locations will be set endogenously by the model to be higher than elsewhere, to cover both the higher commuting costs of those living in distant locations, and the high housing costs of those competing to live locally. This mechanism has been used widely in the LASER model to generate the higher costs of central London employment locations.

(vii) The EUNET model has a time dimension and operates as a quasi-dynamic incremental (or pivot point) model. It is incremental in the sense that it starts from a position that can match the real world, zonal patterns of production, consumption and trade for a base year, to the extent that reliable, consistent, observed data on these patterns is available. Specialised procedures have been developed at ME&P in recent years which control this matching, even where the only data available is at a level of aggregation greater than that at which the model is operated. Once implemented and calibrated for the base year, the model is then operated as a multi-period model into the future. It is deliberately a partial, rather than a full, equilibrium model since some of the processes that it includes, such as floorspace construction and industrial and residential location patterns, can only adjust slowly through time in the real world. Accordingly they are unlikely to ever reach an equilibrium state in practice.

(viii) The way in which the EUNET model is currently designed is that it will be linked to a standard UK macro economic model to provide a partial equilibrium measurement of the impact of transport improvements. This approach is discussed in more detail in the description of EUNET in Annex C.

CONCLUSION

6.3.5 The review above suggests that the MEPLAN package through extensions to the EUNET application could be used as a platform on which a realistic empirical example of the V&G approach could be cost-effectively developed for the Trans-Pennine Corridor Region. Other than the explicit representation of economies of scale, all other processes of the V&G approach as specified in their Appendix 2 have already been used in practice in past MEPLAN model applications, so that the risk involved in this research and development task of creating a demonstration model should not be too great. Nonetheless, it would be an innovative project in which a wide range of novel features are all combined simultaneously, so that it would not be a trivial task to complete the model to an acceptable level of calibration and validation.

We have outlined above suggestions for how the representation of imperfectly competitive industries could be introduced into the EUNET model through adopting an aggregate zone level representation, rather than an approach based on a profile of individual firms.

The EUNET model could also be extended into a general equilibrium framework by replacing the existing fixed Leontief input-output technology, by a suitably calibrated set of Cobb-Douglas functions. However, it would seem advisable to first consider the extent to which this extension is needed for all inter-industry transfers, or whether it would be sufficient to just extend the model to make the primary factors of labour and capital be price elastic, along with the existing elastic inputs of transport and floorspace/land.

The representation of the labour supply could be implemented in one of a number of ways in the demonstration model, depending on the primary purpose of the explorations. It could be fixed by region/zone as in V&G, allowing the expenditure by industries on labour to be elastic to the unit price of labour. However, we believe it would be preferable to fix the supply of labour only for the study area as a whole, allowing the households who provide the labour to be free to relocate among zones as a function of the current availability of housing, and of its endogenously determined market cost. At the next level of complexity, the total number of households within the study area could be allowed to adjust to specific transport policies through differential rates of migration, though this is likely to add significantly to the complexity of the evaluation system and so may not prove worthwhile.

Labour should be segmented by skill/occupation as in LASER if the differential responsiveness of different income groups to price signals is to be properly represented. The representation of the rate of unemployment should be endogenised. When the demand for a particular labour segment is approaching the available supply, scarcity rents should be applied to choke off excess labour demand from each industry. In reverse, when the demand falls below the available supply, unemployed labour is generated from the slack within the segment. Given the fact that the pattern of location of the households and housing supply in the base year will contain an initial supply of labour with very different skills composition in different zones, the resulting estimated future unemployment rates in the model will generally differ by zone.

All of the elasticity, constraint and rent generation mechanisms required for a sophisticated representation of the labour market through space are available within the MEPLAN package. They have been used extensively in the past to represent the operation of the market for floorspace. They can be applied flexibly both at the level of the zone and of the study area and there is a full accounting system that ensures that money is passed consistently between all actors in the system. Both market and non-market constraints can be applied. Supply constraints such as those on private housing are applied by changes in the monetary cost of housing, whereas constraints in the public housing sector are implemented through a non-monetary disutility mechanism in order to avoid distortions in money flows.

When fully implemented this demonstration model would provide a testbed within which the empirical magnitude of the excess benefits derived from imperfect competition could be analysed. Likewise different approaches to CBA to measure these benefits could be investigated. Since it is integrated with a sophisticated complete network based transport model, it would also provide an opportunity to measure the extent to which these benefits could be captured in simpler models. This could be done by gradually switching off different behavioural mechanisms (such as destination switching, mode switching, etc.) within the model.

The key element that this demonstration model would bring is the ability to produce realistic empirical measurements of the scale of excess benefits that could be expected to result from typical transport measures in typical locations. The existence of such benefits has been identified clearly by the work of V&G, but whether these benefits in practice are of a significant magnitude remains to proved.

It will be clear from the above discussion that the MEPLAN package does not contain any significant inconsistencies or barriers to the adoption of the V&G approach. A substantial part of their representation of markets has been in use for many years in commercial applications of the MEPLAN package. The explicit representation of imperfectly competitive industries could be introduced as explained above. While other key topics such as the representation of floorspace/land, of transport and their evolution through time are developed in the MEPLAN framework in a way that would ensure empirical realism in analysis and results.

6.4 Representing imperfect competition within the DELTA approach[11]

INTRODUCTION

6.4.1 There are two major differences of principle to be addressed in considering how DELTA might represent the imperfections of competition.

Firstly, the DELTA package is more context-specific than MEPLAN or TRANUS. One of the hypotheses underlying DELTA is that different processes of change occur at different spatial levels. The existing package was originally developed specifically as an urban model. Whereas the spatial input-output framework of MEPLAN or TRANUS can be converted from urban to regional by changing the variables represented within that framework, the general structure of DELTA is not immediately convertible to a regional application.

Secondly, the DELTA package is much more strongly quasi-dynamic in nature, as was remarked in Chapter 4. All of the processes within the existing urban package are influenced in one way or another by time-lagged variables, many of which are actually measures of change over past periods rather than simple lagged terms. Some of the processes have delayed effects. There are relatively few simultaneous interactions within the land-use model structure, and most important interactions – for example between the location of residents and the location of employment – only operate when the model is run through a sequence of time periods. The overall design of the DELTA package is therefore entirely opposed to the general equilibrium abstractions adopted by V&G, though not at all in conflict with the underlying issues of market structure as identified, for example, by Krugman (1995).

Work on the DELTA/START application to the Trans-Pennine region and on other proposals have required attention to the additional processes needed to extend DELTA to regional and wider scales of analysis. The following sections summarise current thinking in this direction. This falls into two sections: demographic modelling and economic modelling. The discussion is not intended to outline a complete design, but rather to illustrate the different approach required in this context and the kind of model framework which would result.

DEMOGRAPHIC MODELLING

6.4.2 Research into residential relocation and migration patterns has identified a number of different streams of movement. These range from local moves, dominated by households seeking dwellings more appropriate to their composition and income within one labour market, to national migration, which involves moves between widely separated labour markets, usually in search of better work prospects (though with complications such as moves on retirement).

11 This section is essentially the work of DSC. ME&P do not necessarily disagree with the suggestions as to how the concepts in question might be brought into the DELTA framework, but are not in a position to comment on their feasibility.

The existing residential location process within DELTA corresponds to the local movement process (though it does not explicitly model migration, ie it does not output matrices in terms of of old-location to new-location). To adapt DELTA to a wider system, processes of migration need to be superimposed to move households between different urban systems (in particular, between different labour markets).

In contrast with the approach to economic modelling outlined above, appropriate migration models have been extensively researched and should be fairly readily superimposed upon the existing DELTA design in such a way that migration would respond to already modelled variables such as (un)employment and housing prices. It would not be a requirement of the DELTA approach that this upper-level relocation process should be strictly consistent with the existing local relocation process; both the possibility that individuals or households make different decisions on different grounds, and the imperfect information upon which they act, make it quite possible that their actions are somewhat inconsistent. It is not therefore envisaged that the longer-distance migration streams and the local relocation process should be incorporated into any strictly hierarchical design. For the Trans-Pennine study, which requires a hybrid regional-urban model, the existing processes will continue to apply to local relocation. This will operate at the level of labour market areas, but with open boundaries so that residents can live in one area and work in another.

Migration is wholly excluded from the framework of equations put forward by V&G. It is however critical to the model framework put forward by Krugman (1995).

ECONOMIC MODELLING

6.4.3 The existing employment location functions within the urban applications of DELTA are likewise applicable to essentially local processes of location, where all the zones in question are potential substitutes for one another and where the overall growth or decline of each sector is exogenously determined. This intentionally corresponds to the modelling of a city or conurbation which represents a single local economy, highly open to its economic environment. To connect DELTA urban models of this type into a wider regional model, it is necessary to model (a) the growth or decline of each sector in each locality, as an endogenous function of what is happening to all the sectors in all the areas; and (b) to use the linkages between sectors and areas as the basis for a freight model.

The currently preferred way of adding these elements to the model is to superimpose upon DELTA a spatial-economic model, similar to that in the regional applications of MEPLAN. This would therefore involve a spatial input-output model, which would generate intermediate demands given a pattern of final demands, and would distribute the pattern of trade throughout the Study Area and to and from External Zones. The pattern of trade would determine the demand for freight transport, and would be influenced, inter alia, by the costs of freight movement.

Three features would distinguish this from the MEPLAN application of the same concepts. First, it is envisaged that it would work at a sub-regional level, with the existing DELTA employment location functions continuing to determine the precise location of jobs within each sub-region[12]. Secondly, the input-output model is likely to involve more lagged variables and fewer simultaneous responses. Thirdly, to be consistent with the rest of DELTA, the processes which change capacity over time (in this case, industries' production capacity) should be distinguished from the processes which determine the use of capacity at any point in time. This requires some innovation, because the concept of capacity is generally alien to input-output modelling: the linear relationships involved preclude consideration of the capacity as a form of restraint (or additional cost) on output, whilst the provision of capacity appears only as a form of final demand. (Capacity terms in MEPLAN are generally implemented by using observed or previous production as a proxy).

The thinking behind the introduction of capacity variables is twofold.

Firstly, the provision of new capacity should relate to patterns of investment or reinvestment; these are longer term decisions which may be taken on criteria distinct from those implicit in current trade patterns. The location of investment (and the related subjects of firm formation, dissolution or relocation) and the behaviour of different streams of investment (eg inward vs. local) have been the subject of considerable research. This research seems to have been largely ignored in model building, but appears critical to understanding the processes of change at work in regional economies. From the DELTA point of view, these processes of change are ultimately as important or more important than the trade patterns which result from them. Moreover, to incorporate an explicit model of investment or disinvestment seems much more relevant to policy issues than the V&G assumption of free entry and exit of firms from each region's economy.

The second argument for the inclusion of a capacity indicator relates to market structure and economies of scale, again in a different way from that proposed by V&G but with the same broad objectives. It seems possible that one could describe the heterogeneity of that capacity within a sector and region by a distribution parameter, similar to those used in discrete choice modelling. Given this and a level of total demand, the model could assume a pattern of utilisation, ie could describe the proportions of plant operating below, at or above optimum capacity. This would give a representation of economies and diseconomies of scale, reflecting performance at the firm or establishment level by describing the distribution of activity across the sector and region. A distribution with a small standard deviation will represent the situation where producers and their installed capacity in a sector and region are relatively homogeneous, and capacity can readily be switched between the different products of the sector. A larger standard deviation will represent the situation of more imperfect competition, where the producers are very different, particularly if each has equipment which can only produce particular products or varieties of products. These different conditions should have at least two sets of consequences: one on the heterogeneity of prices charged and the way in which these change under changes in demand, and the other (in the longer term) on the rates of investment and disinvestment within the process described above.

This idea (which is in part a response to the issues raised by SACTRA) still has to be tested in the abstract by development of a detailed design. If it can be made to work even at the mathematical level, it should provide an alternative to the V&G approach of assuming that each firm produces a single variety of product.

12 Note that this is similar to the arrangement whereby the IRPUD urban model of Dortmund was (and possibly still is) linked to a spatial input-output model of the region of Nordrhein-Westfalen, except that it will involve overlapping urban models of several conurbations rather than a single urban model centred on a single city.

GENERAL POINTS

6.4.4 Although the addition of a spatial input-output model to the range of DELTA components means that in some respects it may appear more similar to MEPLAN/EUNET, the overall structure of DELTA will remain quite different and the implications for possible introduction of concepts of imperfect competition are quite different. A discussion of how the specific ideas in the V&G framework could be incorporated into DELTA would be fundamentally inappropriate. A more useful way forward would be to take the dynamic structure of DELTA and the concept of different processes (ie different types of decisions made by various groups of actors) that operate on different time scales, and to consider whether this framework might offer new and different insights into the impact of transport on the changing economic structure and performance of different regions.

6.5 Conclusion

Overall, this discussion tends to confirm that the V&G framework is closer to the "regional" implementations of land-use transport interaction models than has been suggested in some of the discussion prior to this Report. It emerges that a large part of what the V&G model has to offer is already operational in MEPLAN/EUNET. An alternative set of ideas about the same issues is under active consideration for DELTA. An important characteristic of these packages is that they either incorporate or are linked to explicit transport models, and they would therefore offer very considerable advantages in strategy testing over the more abstract treatment of transport proposed by V&G. We return to some of the implications of this in our conclusions, below.

There is considerable flexibility in the ways in which these two packages can be set up. When used in commercial planning studies in a specific study area, there is frequently a need to sacrifice detail on the theoretical side in order to free resources for the spatial detail and comprehensiveness of transport representation that is required. In contrast in a study where the aim was to explore the likely magnitude of excess benefits from transport initiatives, the models could potentially be implemented in a fashion that adopted the key elements of the V&G approach, but within a rigorous empirical framework. This would enable the magnitude of the results to be measured with some confidence, and allow other key features of the real world to be introduced.

Such models could then also be used to explore the extent to which a range of simpler, more traditional model structures could provide empirically based rules-of-thumb that might guide in generating approximate estimates of these excess benefits for actual schemes.

6.6 Creating operational land-use/transport models

The early history of operational land-use/transport models was not a very happy one, culminating in the famous paper "Requiem for large-scale models" by Lee (1973). This showed that although many ambitious models had been initiated, very few had eventually been widely and successfully used by policy makers.

Since then the situation has changed in the sense that there have been packages that have been widely and repeatedly used successfully by policy makers and these are reported below. However, there have also continued to be large and ambitious modelling projects that have never arrived to a successful conclusion in terms of being used for practical planning purposes. The step of moving from a sound theoretical framework to a sound calibrated operational model is a challenging one, given the pitfalls that lurk for the unwary.

The packages that are currently commercially available (including MENTOR which will be available in the autumn) in the UK are listed in Table 6.1. This summarises some of the main operational features of these packages that are described in more detail in Volume II.

Table 6.1: **Land-use modelling packages available commercially in the UK**

Package	Supplier	Content	Data requirements	Data processing	Calibration
DSCMOD	DSC	Static, land-use	Mainly standard Census data	Minimal	Limited
DELTA	DSC	Dynamic, land-use	Broad	Significant	Draws substantially on previous research
MEPLAN	ME&P	Dynamic, land-use & transport	Broad	Significant	Significant
MENTOR	ME&P	Dynamic, land-use	Mainly standard Census data	Minimal	Mainly automated
TRANUS	Rickaby Thompson Associates (see note)	Dynamic, land-use & transport	Broad	Significant	Significant

Note: Rickaby Thompson Associates are European distributors of the TRANUS package.

CHAPTER 7
Conclusions

7.1 Approach to the Committee's questions

In the Terms of Reference for this study we were requested to provide a general overview of the workings of the currently available land-use/transport models and then to answer a number of specific questions on model operation. The general overview is provided in summary form in Chapters 2 to 4 of this report and in more detail on a model by model basis within the Annex. The specific questions are addressed in Chapters 5 and 6 and the key points are summarised here in the conclusions.

To address these questions properly it is first necessary to draw an emphatic dividing line between:

- what the existing *models* currently do; and
- what the *packages* from which the models were constructed could currently do or could potentially in the future do.

It is clear that the existing models do not contain a number of features that this review has shown would help in assessing fully the wider benefits that may arise from transport improvements. One of the major reasons for this is that when these models were originally designed, these features were not those that appeared most important for the studies that commissioned the models.

For example, most of the models we have discussed operate at the urban rather than regional scale. For this reason they place little or no emphasis on the markets for products, since the importance of freight traffic in urban areas is very limited relative to that of passenger traffic. They do however place considerable emphasis on the markets for retail and personal services in order to generate suitable patterns of urban passenger travel, and on the market for property to take account of planning constraints and their impacts on future urban development patterns.

Although many of the existing models would need substantial modifications to enable them to address the assessment issues of importance to SACTRA, our view is that certain of the modelling packages from which they were built, either already have the power, or at least the potential, to address most of these issues. This view is supported by our responses to the questions below raised by SACTRA.

7.2 "Do travel cost savings accrue to commuters or are they passed on to employers via labour market mechanisms?"

There is not a uniform approach to this across models. In many of the set of linked (LLUTM) models discussed in Section 5.4.2 this mechanism is not explicitly included. In contrast, in the ME&P examples of integrated (ILUTM) models commuter travel costs do enter explicitly into the production costs of employers. For example in the LASER application, the assumption made in the model is that employers adjust wages to maintain the standard of living of their workforce after any change (upwards or downwards) in transport costs.

In the current MENTOR and MEPLAN packages there is control over the division of how much of the benefit accrues directly to the commuter and how much to his employer. This may be set differently for direct monetary costs and for non-monetary time or transport quality changes. These packages can be set up by the analyst to model the transfers of cost savings in whatever way is deemed most appropriate.

7.3 "Do the models deal with the "unlocking" effects when parcels of land become available for development as a result of building a new transport link?"

As reported in Section 5.3 some of the models can address this issue at the aggregate level (ie additional development within zones), whilst other research is examining how to address such issues at the more detailed site or parcel level.

7.4 "Can the models handle scale economies in production and distribution and relocation/concentration/agglomeration effects in response to transport improvements?"

Relocation effects are certainly handled in many of the existing models together with agglomeration responses of the service and retail sectors. As discussed in Section 5.2 the models do not distinguish between "new" and "displaced" jobs. Most of the models operate by redistributing production and employment among zones rather than by directly generating productivity gains. Scale economies do not appear to be explicitly included in existing models. Imperfect competition is included, albeit in a different way to that in V&G. The random utility based spatial allocation models can take the local monopolies of location into account.

This set of mechanisms is an area in which the existing models could certainly be improved greatly by bringing in elements from the V&G approach. However, at least one package, MEPLAN, already contains most of the functionality required to represent these behavioural features, as we have discussed in Chapter 6, whilst DELTA is developing in a direction which offers an alternative approach to the same underlying issues. The big challenge lies with collecting the data and selecting or calibrating suitable parameter values that will model these responses realistically. The issue is not a lack of a suitable package in which to model them.

7.5 "What is counted in the benefit indicators of the models and what is omitted?"

In section 5.4.1 a list was provided of six onerous requirements in order for a model to be able to guarantee to measure user benefits accurately and consistently. Wherever a model fails to meet one or more of those requirements above, it must be accepted that the validity of its measure of benefits is less than perfect. Standard transport-only models in use would fall on many of these hurdles, despite their widespread adoption in assessment.

It is also fair to say that as yet none of the land-use models reviewed in this study fully matches up to this challenging set of criteria for a complete set of major behavioural responses. The resources required to do so would have been well beyond those available within the studies in which the models were originally developed. Because of the great variety of behavioural responses and the range of different markets included in a typical operational land-use model, tracking benefits through all these mechanisms as well as through time and space is certainly complex. Furthermore, there has not been a great interest from clients to produce resources to allow this topic to be addressed in depth.

The use of the method of compensating variation to measure the benefits seems to be gaining greater acceptance among modellers as the most appropriate approach across a range of modelling approaches. However, full and consistent applications of this approach in comprehensive operational and-use models are in their infancy. Something of a vicious circle has prevailed in this area. The necessary design, implementation and testing of a sound and robust land-use/transport appraisal method has been hindered by the limited resources available for research and development. This has reduced the immediate usefulness of land-use/transport models for transport assessment, which in turn has reduced the likelihood of obtaining the funds to improve the models to a level where they can be of widespread use.

7.6 "Can the models represent the fact that in certain circumstances transport schemes may bring added benefits to an area, in other circumstances the opposite may occur?"

This behaviour, as discussed in Section 5.1, is embedded in the relationships in many of the existing models, when representing the zonal growth or decline of the use of retail and other services catering for a localised market. The models explicitly represent the competition between firms in different zones for custom from all the clients that could reach them. The inclusion of economies of scale would further improve this representation.

7.7 "Is the theoretical basis of the land-use models consistent with the approach of V&G?"

This has been discussed in some depth in Chapter 6. On the face of it the two appear rather different, but in fact many of the differences are greatly exaggerated by the very different purposes underlying the way in which the models have come about. A large part of what urban land-use models focus on is virtually ignored by the current V&G model, and a large part of what the V&G model focuses on is virtually ignored in existing urban land-use models. The regional economic implementations of packages such as MEPLAN and DELTA have rather more in common with the V&G approach than the urban applications of the same packages, precisely because the regional implementations are designed to focus on similar issues to the V&G model. In summary each approach does what its designers set out to achieve – but their initial aims were quite different.

We do not believe that there are irreconcilable, fundamental inconsistencies between the two approaches, at least at the level of ideas rather than equations. To make this more transparent, we have outlined in Chapter 6 how virtually the full V&G model could be implemented in an operational form within the MEPLAN package, based on extensions to the existing EUNET model. The relationship between the V&G framework and the DELTA package is rather more distant, since DELTA is intended to model change over time in a non-equilibrium system, whilst V&G relates to a static equilibrium. Nevertheless, it is possible to see how the underlying ideas of imperfect competition could be brought into the DELTA approach. Either of these would bring many of the theoretical insights from the V&G approach into an operational modelling framework that also includes the markets for property and services as well as a consistent, precise measurement of the operation of the transport market.

Since the initial version of the V&G approach is lacking an explicit representation of choice of transport modes, traffic congestion or other aspects of the supply of transport, we believe their approach would benefit from being integrated within a modelling framework that provided these. The resulting system would provide a research tool that would be of direct relevance to SACTRA's work. Crucially this would also enable the magnitude of the added benefits from transport improvements to be measured using real world data, rather than based on the hypothetical set of numbers in V&G's examples.

An operational model that combined the relative strengths of both approaches would be of both theoretical and practical use. In particular, it could be used to explore the extent to which a range of simpler, more traditional model structures could provide empirically based rules-of-thumb that might guide in generating approximate estimates of the excess benefits for actual schemes.

7.8 Final points

Our conclusions relate firstly to what kinds of models are appropriate to the analysis of the wider impacts of transport change, and secondly to the way in which new and better models and methods of appraisal should be developed.

There is a wide measure of agreement amongst modellers (within the present team and elsewhere) that one of the keys to the improvement of models is through greater segmentation of the activities represented. This holds both in terms of households or of employment in the land-use model or in trip purpose and traveller type in the transport model.

There is also an evident requirement regarding the spatial extent of modelling. To carry out policy appraisal with the kinds of models considered here, it is essential that the modelled area should be large compared with the transport impact area of the scheme or strategy under consideration. This spatial requirement means that an appropriate model should always appear (by conventional traffic modelling standards) notably wide in its coverage compared with the schemes or strategies to be examined.

Together with the points made above about appraisal, all of this tends to indicate that the existing range of models, and all foreseeable enhancements of them, require the models to be complex and to be spatially very extensive compared with the projects to be examined. This will have different significance between urban and inter-urban transport. Where the scheme or strategy to be examined is in an urban context and will mainly affect passenger travel within the city or conurbation, with the impact on longer-distance travel and freight being insignificant, a model of the city itself and its surrounding labour area will be sufficient. A scheme or strategy of similar physical extent between cities or between conurbations might be significant primarily to longer-distance passenger and freight movements, and might accordingly require a model at the regional scale or even larger.

This implies that no easy answer, ie no quick and simple form of analysis, is on offer in respect of “classic” trunk road schemes or any other relatively small inter-urban proposals. These are generally of a size and cost that does not merit the development of a large-scale model, even of traffic alone. The only valid source of a broader analysis for such schemes will be to make use of large-scale land-use/transport models developed for other purposes (or as part of a wider programme of modelling). Even where such models are available, it will be necessary to develop methods or to agree assumptions as to how the benefits (or disbenefits) of significant strategies should be attributed to individual schemes which may be below the models’ thresholds of significance.

The best of the models which we have reviewed already appear to be capable, in their present forms, of providing valuable answers to some of the questions raised by SACTRA’s current work. With further enhancements, some of which are already being pursued, they would be capable of doing much more. The flexibility and generality of some of the packages means that extending them, for example to represent labour markets in greater depth, could be achieved without the need for any significant modifications to the software. The main effort would relate to data analysis and model calibration and validation.

Whilst acknowledging that we are far from disinterested in this matter, we would recommend that the Committee, when suggesting possible future directions of development, should capitalise on the experience already available in building operational land-use/economic models which are either linked to or integrated with sophisticated transport models.

From our experience of other model projects, much of which will be directly familiar to SACTRA members, we would also recommend considering a diverse programme of incremental model enhancements, that builds on what is strong and replaces what is weak. This approach we believe is more likely to be successful than a single grand plan to develop a new and ambitious model from scratch.

CHAPTER 8

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Figure 4.4: **Actors and markets in Venables and Gasiorek**