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Review of RAND Europe's Transport Demand Model Systems

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PREFACE

This report has been prepared by RAND Europe in response to a request from TRL Limited, in connection with work TRL is carrying out for the UK Department of Transport, Local Government and the Regions to produce 'User Friendly Multi-Stage Modelling Advice'. The intention of the Advice is to provide appropriate guidance to those involved in forecasting travel demand for regions of the UK.

This document presents a review of modelling studies RAND Europe has undertaken across the world, and the lessons that can be learnt from this worldwide experience for the UK. Six models developed by Hague Consulting Group (RAND Europe incorporated Hague Consulting Group in January 2001) that are considered of particular relevance to the UK have been reviewed. These six models are:

- 'LMS': the Netherlands National Model,
- the Norwegian National Model,
- 'Antonin', the model of the conurbation of Paris,
- 'OTM', the model of the Copenhagen area,
- 'SIMS', the Stockholm model and
- 'STM', the Strategic Transport Model of Sydney.

This report is aimed at readers who are interested in gaining an insight into how RAND Europe's Travel Demand Model systems operate, and the various components which comprise each model system. No specific expertise is required to understand this document, although the concepts will be much more familiar to readers who have some previous experience of transport models.

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1. INTRODUCTION

RAND Europe (RE) recently incorporated Hague Consulting Group (HCG), a company known world wide for its work on multi-stage modelling. HCG carried out a wide range of modelling studies, in Europe and beyond, during its period of operation (1985 – 2000). A number of these models are clearly of interest to those in the UK wishing to learn from world experience in developing UK travel demand forecasting expertise. This report gives the reader insight into the type of input data required to build these models, the types of policy questions these models are able to answer, and the types of outputs that these models can provide.

For the present study, RE has selected six models developed by HCG that we consider of particular relevance for the UK. The description of these models forms the main content of the present report. The models selected are:

- ‘LMS’: the Netherlands National Model,
- the Norwegian National Model,
- ‘Antonin’, the model of the conurbation of Paris,
- ‘OTM’, the model of the Copenhagen area,
- ‘SIMS’, the Stockholm model and
- ‘STM’, the Strategic Transport Model of Sydney.

It cannot be stressed too highly that these model systems are large and complicated constructions, characteristics that are essential to their function in describing the behaviour of large and geographically distributed populations with respect to a wide range of changes in transport policy and exogenous variables.

The reader should note that individual parameter values have not been quoted in this report for a number of reasons. Each model contains several hundred to a few thousand parameters and the definitions of these parameters are interdependent and vary between the systems. The quotation of any of these parameter values requires an understanding of (a) the context in which the parameter applies (b) exact definitions and measurement errors in the explanatory variables they modify (c) the values of the relevant other parameters which apply to related variables.

It is not clear in any case whether the specific parameter values which are present in these six model systems are of value in the UK. For reasons that are explained below, large-scale model systems vary substantially in detail and these detailed variations have a substantial impact on the values of the parameters. It is not likely that a model developed in the UK would have exactly the structure of any one of these six models and the parameter values could therefore be substantially different. In the text below, it is indicated which variables appear in each of the models.

In the following Chapter, an overview is given of the general characteristics of these model systems and their principal components. The similarities and differences between the models – and the reasons for these – are emphasised. In the following six chapters more detailed descriptions are given of the six model systems themselves. In the final chapter, some conclusions from the study are given. Finally selected references are listed.

2. CHARACTERISTICS OF MODEL SYSTEMS

Many transport planning agencies at national, regional or city level use transport demand forecasting models to help in planning transport infrastructure and management policies or to anticipate exogenous developments in travel demand patterns. To address these diverse aims the models need to be as flexible as possible, e.g. coping with forecast horizons from one to thirty years and wide ranges in policy and exogenous development. Of course there are limitations to the applicability of the models in terms of the level of detail, their reliability in dealing with extreme scenarios, the length of the forecast period that can reasonably be considered etc.. Part of the art of model building is to make these limitations as flexible as possible.

The models developed by HCG are examples of this type and have been developed with the intention of maintaining flexibility as far as possible. In this Chapter they are described, addressing their scope, purpose, definition and main components.

2.1 SCOPE

Six HCG model systems have been selected for description in this report. Four are models of conurbations covering a range of size from about 1.5 million (Stockholm) to 11 million (Paris), i.e. representative in size of many UK conurbations. The Netherlands National Model (LMS) covers an area containing 16 million people and would be representative of a major regional study area such as South-East England. Finally, the Norwegian National Model illustrates how the HCG methods apply to a consideration of primarily long-distance traffic such as would be needed for a detailed corridor model.

The forecasting horizons for which the models are used vary also. The LMS, for example, has been applied for forecasting up to 60 (!) years ahead, for short-term runs in essentially base-year conditions and for 'back-casting' to previous years as an audit procedure to test the validity of the model. Most often, however, it is used to forecast 5 – 20 years ahead.

Auxiliary models, such as downsizing of engine capacity in the face of rising fuel costs, are used regularly but are not reported here.

2.2 PURPOSE

The models have been developed for different purposes and this has affected their structure. In Stockholm and in Paris, for example, the main client for model development was a public transport authority and this meant that the models had a clear representation of public transport alternatives. In Stockholm, there was considerable expertise in public transport assignment, so that the representation of these alternatives in the demand model was kept reasonably simple, while in Paris, which has a very complicated public transport network, many different combinations of the main public transport modes (train, RER, metro and bus) were represented explicitly in the demand model itself. Indeed, in Paris the purpose of the model was to break down public transport usage between modes.

In The Netherlands and in Sydney, the models have been explicitly aimed at covering a wide range of policy and infrastructure analyses, so that there is no specific focus on any one aspect.

The Norwegian model was initially developed to support a project on climate change, which had the consequence that the level of geographical detail in the model could be low, which allowed the use of existing data sources with low levels of geographical detail. Later, however, the model began to be used to analyse specific projects and work was undertaken to increase its geographical representativeness.

The Copenhagen model was developed over a period of several years to support studies of light rail, road and heavy rail proposals. For each of these specific issues, new data was collected (based on Stated Preference interviewing) but the data from the previous studies was also re-used in the model estimation. Thus the final data base on which the current version (OTM 4.0) of the model is based includes data from a number of different SP surveys, local screenline surveys and the National Travel Survey. The model, initially focussed on light rail, has become more widely applicable.

It is a general characteristic of the models that their applicability has increased as time has passed. Another general characteristic is that the models tend to have relatively long lives, i.e. the investment required to set them up is recovered over a relatively long period: the LMS has now been in use for over 15 years and has been substantially updated on several occasions. The reasons underlying these characteristics, which of course help enormously in giving a positive evaluation of the models, are their ability to be flexible in coping with new policy ideas and their consistency in giving reasonable responses.

2.3 DEFINITIONS

The definitions used in the models also vary somewhat, although there is a considerable degree of consistency.

The models all deal with the demand for travel as 'tours', i.e. complete journeys from leaving home until returning home again. This definition is now widely accepted as being the most appropriate for travel demand modelling, since the earlier 'trip' definition (i.e. a one-way movement between origin and destination) omits a number of essential timing and mode interdependencies between outbound and return travel. This definition was used in the initial specification of most of the models but has only been achieved in the recent update of the Copenhagen model and trips are still used for modelling business travel in that model.

The level of treatment of non-home-based travel varies. In most cases, non-home-based business travel is modelled and in Stockholm this is extended to include all travel that is part of work-related tours.

The modelling of travel as tours brings the models a major step from trip modelling towards an activity-based approach to modelling transport demand. The activity-based approach is generally becoming widely accepted as the appropriate way to recognise the 'derived demand' nature of travel and to bring in changes in out-of-home activity participation and organisation which may result from major transport changes or from exogenous effects. In the Stockholm model in particular, further steps are taken by modelling explicitly the 'party' for some travel purposes, such as shopping, where the task can be allocated to a household member, or group of members, who have more time or better accessibility to shops, and to model the choice of organisation of travel, for, say, shopping, as part of work tours, whether as a lunch-time sortie, a detour on the way to or from work, or as a separate home-based tour.

The models are in principle disaggregate as far as possible in their treatment of data. In Copenhagen, however, aggregate data from estimated (part observed) trip tables is used for the estimation of the destination choice (distribution) model. This issue is one of data availability: disaggregate data gives in principle more information, but may not be available in sufficient volume for modelling work. It is for this reason that aggregate data has been used for some of the modelling in Copenhagen.

In all of these systems, a number of travel purposes, typically 5-10, are defined and these are modelled essentially independently. Typically, commuting, business travel and education are modelled separately, while the remaining travel may also be divided into 2 to 5 purposes. The division of purposes in these systems is more extensive than in typical systems developed earlier or using aggregate methods.

Similarly, the number of travel modes (or 'mode-combinations' for tours using multiple modes) represented in the systems is larger than in many other models. A minimum of four modes (Copenhagen) and a maximum of 13 (Paris) are represented separately, although not all of these are necessarily available for any given journey. The recognition of these separate modes allows the availability and level of service to be determined more accurately, while it also gives more useful output in many cases.

However, the most dramatic increase in the level of detail in these models relative to earlier models is in the definition of person types. Rather than simply distinguishing car owners (or car availables) from the rest of the population, these models incorporate dozens or even hundreds of person types. These definitions allow more accurate modelling of transport availability and level of service (e.g. licence holding, car ownership affecting the availability of car passenger travel, fare concessions), allowance for differences in behaviour (e.g. variation in time-cost trading by income, preference among younger men for cycling) and also allow reporting to be more detailed and better aligned with the requirements of policy makers.

A consistent feature across the models (except Copenhagen) is the use of prototypical sampling as a means of forecasting the distribution of key variables within the future population. By applying this reasonably simple procedure it is possible to generate realistic forecasts of the socio-economic details required to apply the models.

A final general feature is the widespread use in the models of travel cost in a logarithmic form. This has been found consistently to give a better explanation of observed behaviour and is consistent with the finding in many national value-of-time studies – including that for the UK – that values of travel time increase consistently with the distance travelled. The log cost formulation is a clear point of difference from previous models. Note that it is not possible to state a single value of time for a model with this formulation.

2.4 MODEL COMPONENTS

This section outlines the key features of the model forecasting components for each of the six model systems, and allows a direct comparison between each model system. The model components are then described in greater detail in Chapters 3 to 8. The sequence in which the model components are presented corresponds to the order in which they are normally implemented; outputs from earlier models form inputs to subsequent models.

An issue that is discussed in this section is the decision in each model as to whether a particular model component should be included. This varies across the models for reasons of local policy interest, data availability and even the opinions of the study teams.

2.4.1 Licence Holding Models

Table 1 summarises the key-features of the licence holding models used in the six model systems. The models, which are not present in all of the systems, use aggregate cohort forecasting to obtain overall forecasts of licence holding for each age-sex cohort, then use these forecasts to constrain the output of disaggregate models which are thus responsible for modelling the distribution of licence holding over household and person types.

A technique developed for the LMS is to use one disaggregate model to model licence holding by the head of the household and their partner, and then use a second disaggregate model to model licence holding by any other adults in the household. As such the LMS licence holding models are both household and person based. The same approach has been used for a number of the model systems subsequently developed. The features of the models detailed in Table 1 are as follows.

Data source: the data source for disaggregate models is generally a detailed travel survey diary. Travel survey diaries normally record the licence holding of all adults in the household.

Model records: this details the total numbers of observations used in estimation to give an idea of typical sample sizes.

Disaggregate models: this defines the model form of the detailed disaggregate cross-sectional licence holding models.

Aggregate model: this defines the form of the aggregate licence models used to forecast total licence holding and model long-term changes in licence-holding.

Income terms: indicates whether variations in licence holding with income are modelled.

Table 1: Key Features of Licence Holding Models

	LMS	Norway	Paris	Sydney
Data Source	National Travel Survey	National Travel Survey	Paris Area Travel Survey	Household Travel Surveys
Model Records	10,734 households	4,005 households	9,835 households	13,904 households
Level of Detail	Disaggregate at the household / person level	Disaggregate at the Household / person level	Disaggregate at the Household / person level	Disaggregate at the household / person level
Disaggregate Models	One for head of household & partner, one for other adults	One for head of household & partner, one for other adults	One for head of household & partner, one for other adults	One for head of household & partner, one for other adults

Aggregate model	Cohort model	Cohort model	Cohort model	Cohort model
Income Terms	Household	Household	Household	Household

There is no licence holding model in the Copenhagen or Stockholm model systems. Observed licence holding is used in these models. In these cases the local analysts believed that licence holding was so high that explicit modelling was unnecessary.

2.4.2 Car Ownership Models

Table 2 summarises the key-features of the car ownership models used in the six model systems. Advanced model systems generally model car ownership at the household level. Typically the output from the licence holding model is used as an input to the car ownership model, so that forecast changes in licence holding impact upon forecast car ownership. In this way an important part of the time trend in car ownership is modelled in a proper way.

The features of the models detailed in Table 2 are as follows:

Data source: the data source for disaggregate models is generally a detailed travel survey diary. Travel survey diaries normally record household car ownership.

Model Records: this details the total numbers of observations used in estimation to give an idea of typical sample sizes

Level of Detail: this defines the level of disaggregation of the models.

Aggregate Adjustment: details if total car-ownership projections are adjusted to match projected aggregate totals.

Model Alternatives: details the possible car-ownership outcomes.

Income Terms: details if car-ownership forecasts vary with income.

Table 2: Key Features of Car Ownership Models

	LMS	Norway	Paris	Stockholm	Sydney
Data Source	National Travel Survey	National Travel Survey	Paris Area Travel Survey	Stockholm Travel Study	Household Travel Surveys
Model Records	not available	4,005 households	9,835 households	not available	12,368 households
Level of Detail	Disaggregate at the household level	Disaggregate model of car ownership and usage	Disaggregate at the household level	Disaggregate at the household level	Disaggregate at the household level
Aggregate Adjustment ?	Yes	No	No	No	No
Model Alternatives	0 cars 1 car 2+ cars	{ 0 cars, 1 car, 2+ cars } * kilometrage	0 cars 1 car 2+ cars	0 cars 1 car 2+ cars	0 cars 1 car 2 cars 3+ cars
Income Terms ?	Household	Household	Household	Household	Household

* In the Norwegian model, car ownership *and usage* (kilometres per year) are modelled simultaneously in one variant of the model. The standard model system, however, was a different variant suitable for contexts in which changes to car running costs are marginal.

There is no car ownership model in the Copenhagen model. Car ownership by zone is used instead.

In the Sydney model, company car ownership is modelled separately. The output from the household company car ownership model (0 company cars, 1 company car, 2+ company cars) is used as an input to the total car ownership model.

2.4.3 Tour Frequency Models

Table 3 summarises the key features of the tour frequency models used in the six model systems. Advanced tour frequency models are generally defined at the person level. The output from the licence holding and car ownership models are used as inputs into the tour frequency models. The models then predict the number of tours made per person per day, which in turn forms the input to the mode-destination models. The features of the models detailed in Table 3 are as follows:

Data source: the data source for disaggregate models is generally a detailed travel survey diary, which details the number of tours made by each person in the household on the survey day.

Model Records: this details the total numbers of observations used in estimation to give an idea of typical sample sizes.

Level of Detail: this defines the level of disaggregation of the models.

Income Terms: details whether tour frequency forecasts vary with income.

Accessibility Effect: indicates whether the tour frequency model predicts higher tour frequency rates from more accessible origin zones.

Table 3: Key Features of Tour Frequency Models

	LMS	Norway	Paris	Copenhagen	Stockholm	Sydney
Data Source	National Travel Survey	National Travel Survey	Paris Area Travel Survey	National Travel Survey	Stockholm Travel Study	Household Travel Surveys
Model Records	115,000	5,696	22,421	12,800	not available	33,565
Level of Detail	Disaggregate at the Person level	Disaggregate at the Person level	Disaggregate at the Person level	Disaggregate at the Person level[1]	Disaggregate at the person or household level	Disaggregate at the Person level
Income Terms	Household	Personal & Household	Household Only	No	Household only	Personal & Household
Accessibility Effect	No	Yes[2]	No	Yes	Yes	Yes

The Stockholm model uses complicated model structures which explicitly consider the interactions between each individual in the household when modelling tour frequency.

1 Applied at the aggregate level, however.

2 Long-distance model only.

2.4.4 Mode-Destination Choice Models

Table 4 summarises the key features of the mode-destination models used in the six model systems. Advanced mode-destination models are generally defined at the person level, and consider mode and destination choice in a single model, reflecting the strong interaction between the two choice processes. The output from the licence and car ownership models feed into the mode-destination models, so that changes in licence holding and car ownership impact upon the forecast mode and destination shares. The features of the models detailed in Table 4 are as follows:

Data source: the data source for disaggregate models is generally a detailed travel survey diary. Typically households record all travel made by household members on a single survey day. As well as collecting travel patterns, travel survey diaries collect detailed person and household information, which allows inter-personal and inter-household variations to be accounted for in modelling.

Model records: this details the total numbers of observations used in estimation to give an idea of typical sample sizes.

Level of detail: this defines whether the model is aggregate or disaggregate;.

Modes: the numbers of modes modelled.

Destinations: the number of destinations modelled.

Purposes: the number of travel purposes modelled.

Unit of travel: details whether the model is trip or tour based.

Destination sampling: details whether destination sampling has been used in estimation for efficiency where the number of mode-destination alternatives is high.

Income terms: details if variations in cost sensitivity with income are modelled.

Cost forms: details the cost formulation used in the models. This may vary between model purposes.

Table 4: Key Features of Mode-Destination Models

	LMS	Norway	Paris	Copenhagen	Stockholm	Sydney
Data Source	National Travel Survey	National Travel Survey	Paris Area Travel Survey	Multiple sources RP and SP	Stockholm Travel Study	Household Travel Surveys
Model Records	190,000	6,056 / 27,746	32,430	not available	not available	31,890
Level of Detail	Disaggregate at the person level	Disaggregate at the person level	Disaggregate at the person level	Distribution aggregate, mode-choice disaggregate	Disaggregate at the person / household level	Disaggregate at the person level
Modes	Five	Four / Five	Thirteen	Seven	Five	Nine
Destinations	1,308	454	850	601	850	884
Purposes	Five	Seven / Five	Ten	Four	Six	Seven
Unit of Travel	Tour and trip for NHB	Tour	Tour	Tour and trip	Tour and detour	Tour and detour
Destination Sampling ?	Yes	No	Yes	No	Yes	Yes
Income Terms ?	Yes	No	Yes	No	not available	Yes
Cost Forms	Log-cost	Linear-cost Log-cost Cost/Income	Log-cost	Linear-cost	not available	Log-Cost

Note that the Norwegian model system, separate models have been estimated for short-distance (up to 100 km) and long-distance (100 km or more) travel. The short-distance Norwegian model is a mode-*distance* choice model, where the alternatives are mode and distance band, i.e. individual destinations are not modelled.

3. LANDELIJK MODEL SYSTEEM (LMS)

3.1 OVERVIEW OF MODEL SYSTEM

The Netherlands National Model System (LMS) was probably the first disaggregate national travel demand forecasting system. The model system has been in use since 1986, and has been extensively updated and extended through during its lifetime.

The model system was developed for the Dutch Ministry of Transport and Public Works in 1984-85 with the objective of supporting the Second Transport Structure Plan (SVV-II). In the subsequent period, the model system established a market for applications supporting policy analysis for national road and railway planning, whether infrastructure, pricing or management, or land use policy.

The success of the LMS was such that a New Regional Model (NRM) was established in 1990, using essentially the same models as the LMS, to allow regions to make more detailed forecasts for the evaluation of regional policy. By developing the NRM from the LMS, regional forecasts can be made in a manner which is consistent with the national forecasts. To date, six regional applications of the model have been made, covering a large part of the Netherlands.

In 1996, the 'ProMiSe' system was developed from the LMS for Netherlands Railways. This system utilised data from the LMS, but focussed on specific railway aspects of traveller behaviour.

The LMS was constructed to make traffic forecasts for the medium and long term. The main objectives of the LMS were to provide insight into changes in the mobility patterns of the Dutch population and to predict traffic flows on the Dutch road and railway networks.

The application of the LMS takes place within the context of spatial, socio-economic and demographic changes modelled by a given *scenario*. For a scenario, the LMS provides forecasts that relate to:

- National and regional levels;
- Car-driver, car-passenger, train, BTM[3] and slow modes;
- Average working day, peak and off-peak periods.

The forecasts produced by the LMS for a given scenario are responsive to changes in:

- Land-use factors;
- Accessibility characteristics;
- Socio-economic factors;
- Demographic factors.

Through a number of auxiliary models, LMS is also responsive to changes in work practices, including telecommuting, and changes in the type of car in the car fleet. Car ownership is sensitive to expenditure on other household necessities, such as housing, subsistence and so on.

The output results from the LMS are directly linked to policy criteria with respect to mobility, the economy, safety and the environment. This means that the LMS is well suited to analyse the impact of specific policy measures. A key property of the LMS in this respect is that is can produce results for different travel purposes and for specific groups of people and households. This makes it possible to assess the impact of policy measures on specific groups in the Dutch population.

The forecasts generated by the LMS for a given forecast year are calculated as changes relative to the reference year. For the reference year, matrices of *observed* trips have been determined, and hence all model forecasts are derived by calculated changes relative to a known base case.

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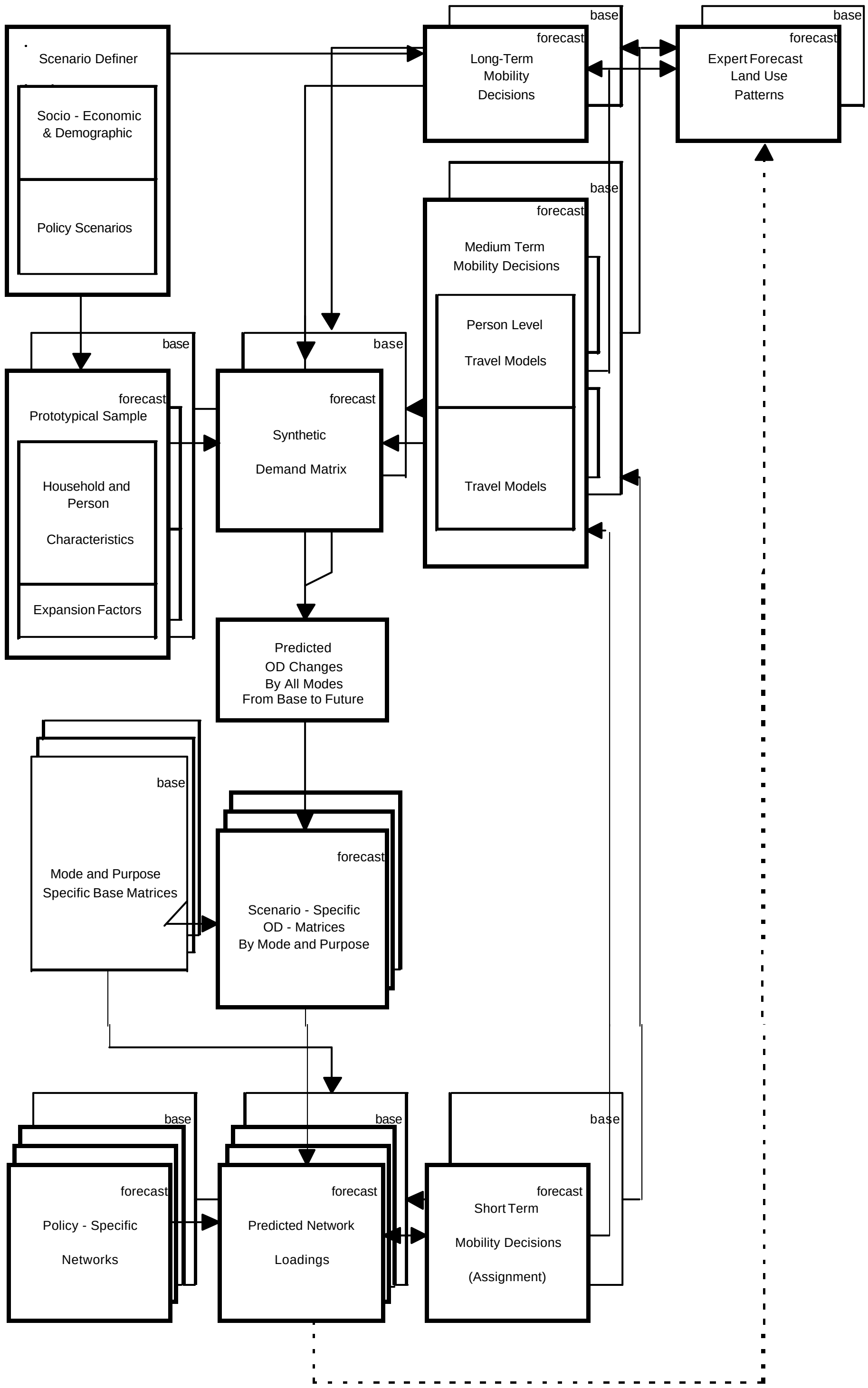
3 BTM: bus, tram and metro.

A total of 1308 zones are distinguished in the model, providing a detailed representation of spatial travel patterns in the Netherlands. The zoning system used is illustrated in Figure 1. The zone sizes are smaller in the more densely populated urban areas, such as in the highly urbanised Randstad area in the West of the country, and larger in more sparsely populated areas, such as in the largely rural North.

Figure 1: LMS Zoning System

3.2 MODEL STRUCTURE

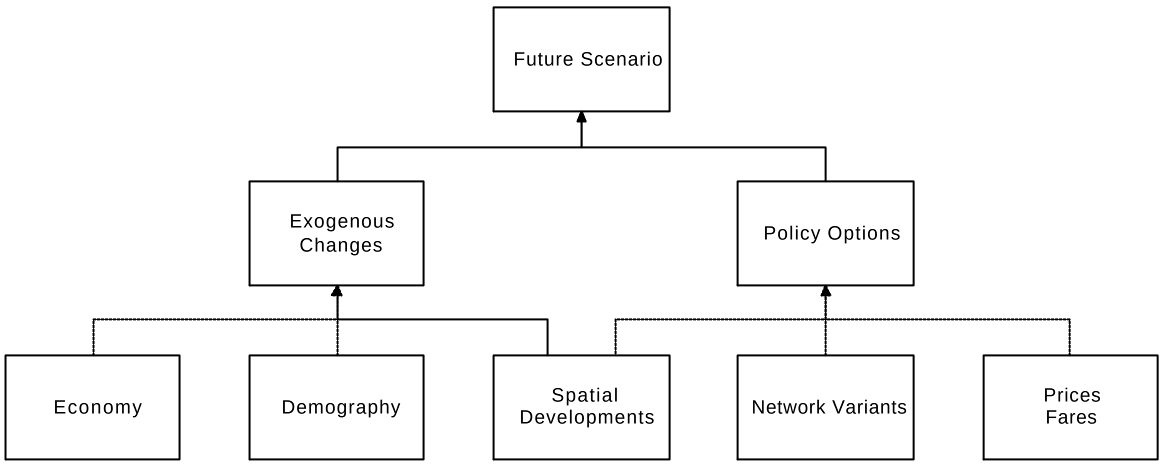
Figure 2: LMS Model Structure



3.2.1 Model Inputs

The socio-economic, demographic, spatial and network conditions necessary to define the model inputs are together termed a *scenario*. For a given scenario both exogenous changes, such as changes in population, and specific policy options, such as the construction of new links or strategic rationing of parking spaces, must be defined. These changes are illustrated diagrammatically in Figure 3.

Figure 3: Scenario Components



Socio-economic and demographic developments cannot be directly influenced by transport policy, and as such form exogenous inputs. To some extent this is also true of the spatial situation. The inputs are determined using forecasts produced by other government organisations and departments, for example projections of car ownership, economic growth and regional developments in population and employment. For large projects such as the Environmental Plan, consistency is achieved by iterating between departments, showing accessibility consequences of land use plans to trigger the development of new plans.

The traffic system and rules and conditions for its use, and to a certain extent the spatial situation, can be influenced by transport policy. Together these components form the policy options.

3.2.2 Model Outputs

The final output from the LMS is loaded road and rail networks, together with OD matrices for the BTM and slow models. These outputs are capable of being disaggregated into different market segments for evaluation purposes. For example, output for specific journey purposes, or specific traveller types, can be identified.

The LMS generates a large volume of disaggregate data as output. It is possible to determine interim outputs prior to network loading to provide fast approximations for policy testing. Examples of these outputs include growth in kilometres, numbers of tours, total travel time and cost by mode, purpose and segment.

3.3 MODEL COMPONENTS

3.3.1 Prototypical Sample

The prototypical sample is a sample of 50,000 households, drawn from the 1995 OVG National Travel Survey data. The sample contains sufficient household and person information to apply the disaggregate models of licence holding, car-ownership, tour frequency and mode-destination choice described in the following sections. The households in the prototypical sample have been split into 335 categories, consisting of 67 household categories and five household income bands:

- Three age of head of household categories: aged under 35, aged 35-65, aged 65+;
- Five household size categories: one, two, three, four, five plus persons in household;
- Eleven worker categories: zero, one and two plus workers, and various different combinations of gender and full/part-time split between the workers.

Note that only certain combinations of these categories are possible. Care has been taken to ensure that there are sufficient households in each category to make statistically significant statements about the travel behaviour of each category, and the categories chosen to allow the sample to be expanded to *both* base and forecast population totals.

To apply the prototypical sample to the population as a whole in a scenario run, 18 target variables are defined for each zone. These zonal targets incorporate projected changes in population by age and sex, employment by sex, employment by worker type, and household income. The targets are then used to re-distribute the population by age and household composition amongst the 67 household categories using an error minimisation technique.

Once the distribution is complete, expansion factors for each household category can be defined, so that when the expansion factors are applied to the prototypical sample, the weighted number of households reflects the zonal total. Thus the prototypical sample is applied to different scenarios through the application of new expansion factors to reflect changes in population and employment composition and distribution.

3.3.2 Licence Holding Models

Licence holding is forecast by applying a disaggregate model to the households in the prototypical sample. The first model predicts the licence holding of the two main adults in the household. A second model predicts the licence holding of any other adults in the household, conditional upon the licence holding of the first two adults.

The model terms in the licence holding model for the two main adults are as follows:

Table 5: LMS Two Main Adult Licence Holding Model Terms

	Model Alternative			
Model Variables	No Licence	First Adult Holds Licence	Second Adult Holds Licence	Both Adults Hold Licences
Monthly Income	√			√
Higher Education		√ (1st Adult)	√ (2nd Adult)	√ (Both)
Working Adults		√	√	√
Aged over 45			√ (2nd Adult)	√ (2nd Adult)
Aged over 65		√ (1st Adult)		√ (1st Adult)
Number of Children in Household		√		√
Household Head is a Woman				√
Place of Residence is not in the Randstad				√
Place of Residence is not a Major City				√

If there is only one adult in the household, then only the first two alternatives are available, of course.

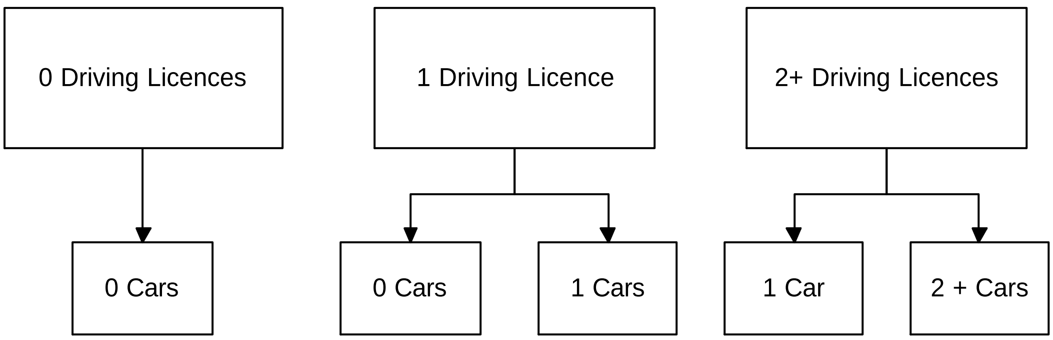
A separate model determines the licence holding of any subsequent adults in the household. The variables in this model are other licence holding in the household, level of education, age, sex, region and degree of urbanisation.

Once the disaggregate models have been applied and the total (weighted) number of licences determined, the output is divided into eight categories according to the age and sex of the individual. The results are compared with control totals produced by an aggregate cohort model of licence holding, and adjustment constants added as necessary.

3.3.3 Car Ownership Models

The car ownership model predicts car ownership at the household level, dependent on the outcome of the licence holding model. The alternatives available to a household with a given number of forecast licences are as follows:

Figure 4: LMS Car Ownership Model Alternatives



By making the possible car ownership outcomes conditional on licence holding, the number of possible alternatives is reduced, simplifying the model structure.

The model terms in the car ownership models are as follows:

Table 6: LMS Car Ownership Model Terms

Model Variables	Car Ownership Model: 0 / 1 + cars	Car Ownership Model: 1 / 2 + cars
Disposable monthly income	√	√
Reside in a rural province	√	√
Reside in an area with a low degree of urbanisation	√	√
Driver is a woman	√	
One or more workers in household		√
Number of persons aged under 12		√
Number of persons aged 12 – 18		√
Person holding licence is over 45	√	

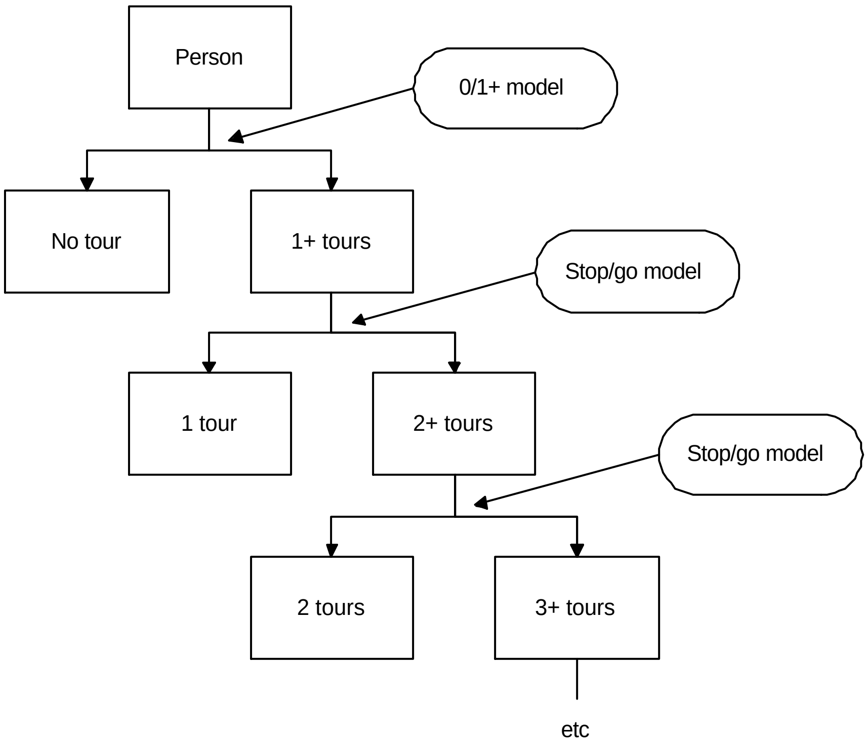
In the base year, the constants in the have been calibrated at the zonal level, reflecting geographical variations in car ownership. 'Disposable income' or 'income remaining' differs between the different numbers of cars owned. Roughly, it is gross income *less* household essential expenditure *less* vehicle necessary expenditure for the vehicle fleet in question.

In a scenario model run, the constants in the disaggregate model can be adjusted so that total car ownership is consistent with the projections of an exogenous aggregate car ownership model. However, the adjustment procedure is applied in a manner which retains the geographical variations of the disaggregate models.

3.3.4 Tour Frequency Models

The tour frequency model uses two linked models to predict the total number of tours made by an individual for the travel purpose in question. The first model (the 0/1+ model) predicts whether the individual will make any tour that day, i.e. whether they will participate in the relevant activity that day. The second model (the stop/go model) predicts whether further tours will be made, given that a specific number have already been made. The model structure is illustrated in Figure 5.

Figure 5: LMS Tour Frequency Model Structure



Tour frequency models have been estimated for adults for each of the following purposes:

- Commuting: working individuals;
- Commuting: non-working individuals;
- Other work-related: working individuals;
- Other work-related: non-working individuals;
- Education: students;
- Education: non-students;
- Shopping and private business;
- Social, recreational and other.

Additionally, a further model predicts the frequency of non-home-based business trips.

For children (aged under 12), frequency models have been estimated for two purposes:

- Education;
- All other tours.

The terms in the frequency models vary between purpose. The terms include numbers of persons in the household, numbers of workers, occupation, income, licence holding, car ownership, occupation, sex, age and level of education. The output of the licence holding and car ownership models feeds directly into the tour frequency models.

Accessibility terms were tested in the model, to investigate whether more accessible zones had higher tour frequency rates, but significant terms were not identified.

3.3.5 Mode-Destination Models

There are a total of eight mode-destination models in the LMS, six for adults, and two for children. The numbers of observations used in model estimation by purpose is detailed in Table 7.

Table 7: LMS Mode-Destination Observations by Purpose

Purpose	Observations
Home-Work	38,901
Home-Business	2,338
NHB[4] Business	10,320
Home-Education	10,630
Home-Shopping	39,457
Home-Other	61,601
Primary Education	15,427
Other Children's Travel	16,543

[4] NHB: Non-Home-Based.

The implemented models use a detailed segmentation to account for inter-personal variation, using a total of 490 person types, segmented by:

- Car availability and licence holding;
- Age;
- Employment status;
- Sex;
- Income, using five different bands.

The actual segmentation used varied according to model purpose. For all model purposes, log-cost was found to give a significantly better model fit than linear-cost.

In a recent upgrade of the LMS model system, the mode-destination models have been re-estimated using different tree structures for each model purpose, as illustrated by Figures 5 to 7.

Figure 6: Tree 0 - Multinomial Mode and Destination Choice

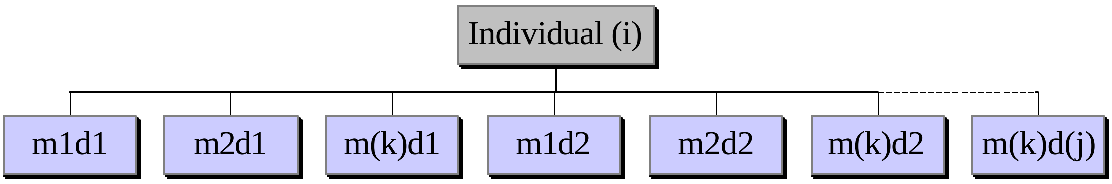


Figure 7: Tree 1 - Mode Choice 'below' Destination Choice

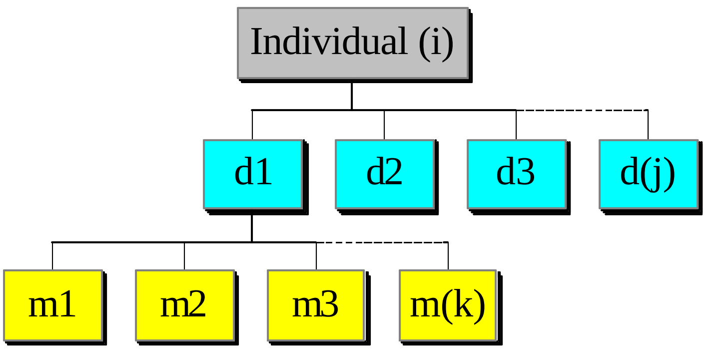
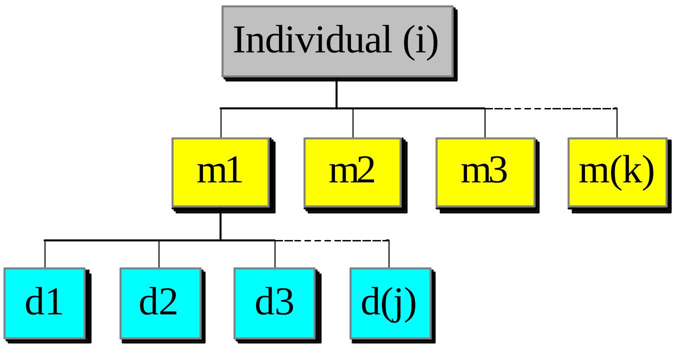


Figure 8: Tree 2 - Destination Choice 'below' Mode Choice



Tree 1 implies that mode choice is more elastic (easier to switch) than destination choice. This structure has been adopted for home-work, home-business and NHB business models, and is felt to be plausible for these purposes.

Tree 2 implies that destination choice is more elastic than mode choice. This structure has been adopted for home-shopping and home-other models, and is felt to be plausible for these purposes.

3.3.6 Assignment

For assignment, the LMS uses a specially written procedure, QBLOK. This procedure has been found to be necessary because of the high levels of congestion in the base year and the very high levels in some forecast scenarios. The specific features of this method is that it uses an essentially 'static' method – i.e., with a uniform flow throughout the assignment period – to represent traffic features that can normally be modelled only in dynamic procedures. Specifically, QBLOK is able to represent the formation and dissolution of queues and the impact on crossing traffic of standing traffic.

Further detail on QBLOK and tests of its performance are available in published material but are not the primary focus of the present study.

4. NORWEGIAN MODEL SYSTEM

4.1 OVERVIEW OF MODEL SYSTEM

The Norwegian model system was developed in 1990 in response to increasing international concern about the Greenhouse Effect. The main objective of the project was to create a forecasting system capable of assessing the success of carbon-dioxide control measures in Norway. A secondary objective was that the forecasts of transport demand should be input to, and consistent with, the macroeconomic forecasts produced by the Norwegian Central Bureau of Statistics (SSB).

The model system was developed by Hague Consulting Group, working in a joint venture with the Institute of Transport Economics (TOI) in Oslo, to predict fuel use and emissions from private travel in Norway between 1985 and 2025. The system was designed to be sensitive to the following carbon-dioxide control measures:

- increased fuel taxes;
- vehicle purchase tax rates favouring fuel efficient vehicles;
- improved public transport;
- land-use planning in urban areas.

The system was designed to reflect changes in demography and mobility over its forecasting horizon, and to show sensitivity to the fixed and variable costs of the different models of private travel.

In order to create a system that shows sensitivity to different policies, and their impacts upon different parts of the population, it was decided to develop a system using a high level of disaggregation. Furthermore, while car is the major source of carbon-dioxide emissions from private travel, it was considered necessary to consider competition from public transport and slow modes in order to model the private travel market accurately.

In particular, prominent modes in Norway are air and boat travel, also substantial contributors to carbon dioxide emission.

Given these considerations, it was decided to adopt the general structure of the LMS, described in Chapter 3 (in a more recent version that than used as a basis for the Norwegian system). However to reflect the different objectives of the Norwegian system, two major changes were made to the LMS structure:

- The environmental problem resulting from vehicular emissions is proportional to overall levels of demand, and so it is not necessary to produce forecasts with a high level of spatial detail. As a consequence, the detailed trip matrices, network assignments and link detail used in the LMS were not required.

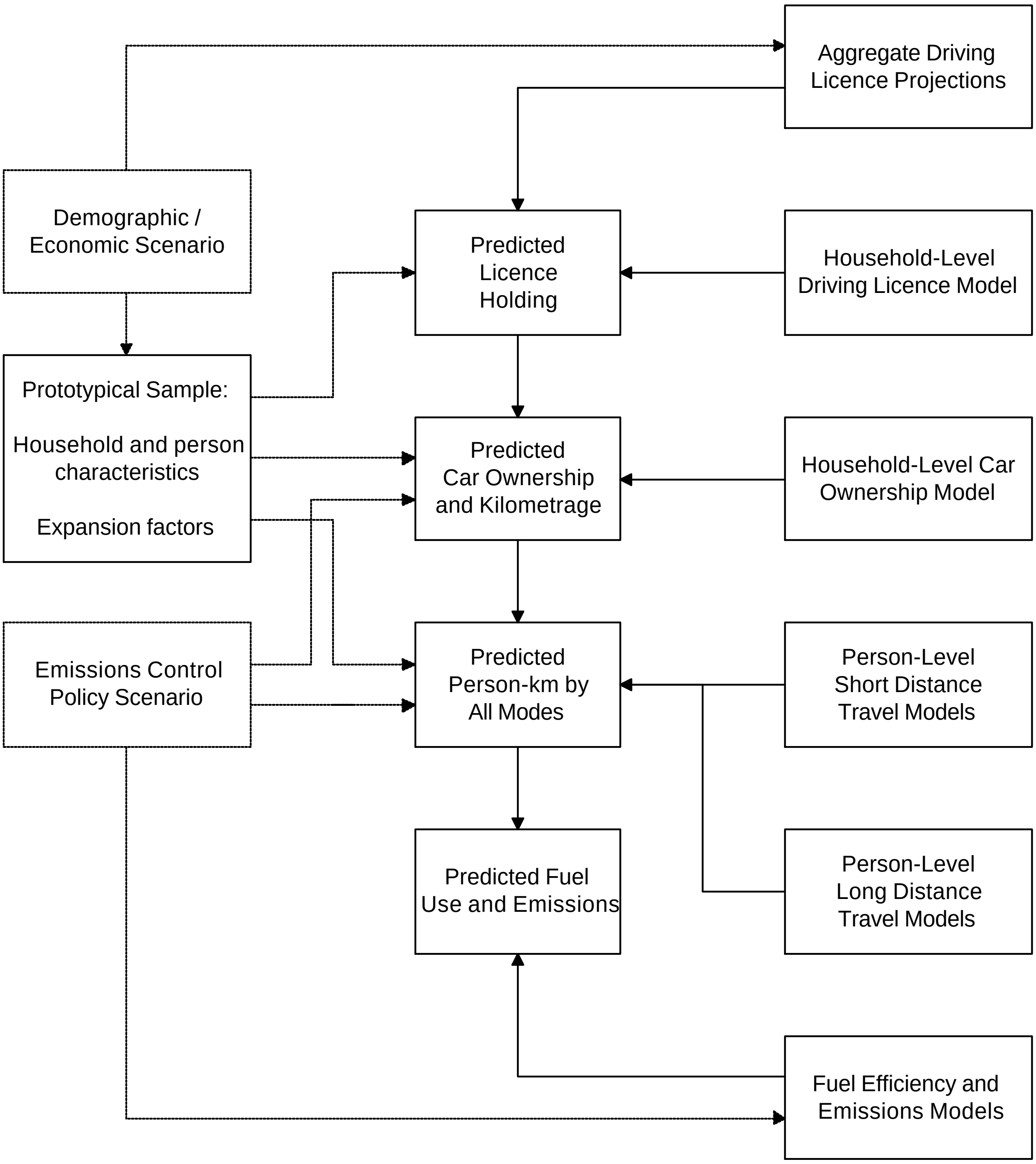
- A key output from the system is car kilometrage. Given that some policies might have a more than marginal effect on car costs, it was seen to be desirable to have a variant model to predict car ownership and usage using a single consistent economic framework, in addition to the standard approach of LMS.

Further, because of the limited availability of certain data, amendments were made to the structure of the model, as described below.

4.2 MODEL STRUCTURE

The model structure used in the Norwegian model system is outlined in Figure 9. The model inputs are denoted by a dashed box, and the component models are denoted by a thick lined box.

Figure 9: Norway Mode l Structure



4.2.1 Model Inputs

The model inputs together define the model scenario. Model scenarios are described in Section 3.2.1; while there are differences between the LMS and the Norwegian model system, the concept of a scenario is common to both model systems. As in the LMS, the Norwegian model system has to account for exogenous changes in income, population and employment which are not controlled by environmental policy.

In the Norwegian model system, the policies tested using scenario runs obviously have an environmental emphasis, and the system has been set up to enable such policies to be tested directly.

4.2.2 Model Outputs

The key outputs of the Norwegian model system are predicted car ownership and usage, predicted person kilometres for all modes and predicted fuel use and emissions.

4.3 MODEL COMPONENTS

4.3.1 Prototypical Sample

The prototypical sample was drawn from the 1984/85 Norwegian National Travel Survey. In total 2,942 households were included in the prototypical sample. Approximately three-quarters of the households were drawn from across Norway, with the remaining quarter drawn from the Oslo area. The prototypical sample contains sufficient household and personal information to apply the disaggregate models of licence holding, car-ownership and usage, and short and long-distance travel.

In total 30 household categories were used:

- Age of head of household (under 35, 35 to 65, 65+);
- Household size (1, 2, 3, 4, 5+);
- Employment status of head of household and their partner where applicable (neither, male employed, female employed, or both employed).

The prototypical sample is then applied in the same way as in the LMS, described in Section 3.3.1.

4.3.2 Licence Holding Models

The disaggregate models of licence holding were based on those developed for the LMS, described in Section 3.3.2. The main model predicts the licence holding for the head of the household and their partner, if one exists. A sub-model is used to predict the licence holding of any other adults in the household.

The model terms in the licence holding model for the head and partner are as follows:

Table 8: Norway Head and Partner Licence Holding Model Terms

	Model Alternative			
Model Variables	No Licence	Head Holds Licence	Partner Holds Licence	Both Adults Hold Licences
Household Income	√			√
Higher Education		√ (1st Adult)	√ (2nd Adult)	√ (Both)
Head Aged over 45		√		√
Partner Aged over 45			√	√
Head Aged over 65		√		√
Partner Aged over 65			√	√
Head Household Employed		√		√
Partner Employed			√	√
Number of Children in Household				√
Number of Adults in Household	√			√
Low Urbanisation	√			√

The model replicates lower licence holding where the head of the household is female. The age terms account for lower licence holding amongst older groups. The number of children in the household increases the probability of double licence holding, as does a low level of urbanisation.

The model for other adults contains similar terms to the head and partner model.

The disaggregate licence holding models are applied to all the households in the prototypical sample. The weighted numbers of licences predicted are aggregated by sex and the following age bands:

- aged 15 - 24;
- aged 25 - 34;
- aged 35 - 49;
- aged 50 - 64;
- aged 65+.

The predicted levels of licence holding by age-sex cohort are compared to the aggregate cohort projections, and adjustment constants added as necessary so that the weighted disaggregate totals match the projected totals.

4.3.3 Car Ownership and Usage Models

The Norwegian model system is unusual in that it has a variant in which car ownership and usage are modelled together. This approach was adopted due to the requirement for accurate vehicle kilometrage forecasts to allow the calculation of vehicular emissions and to represent the impact of fuel price on car ownership, even when car costs are changed dramatically.

The joint ownership and usage model developed was based on the micro-economic theory of consumer behaviour. This theory depicts the household car-ownership decision as maximising utility under a budget constraint. The costs of car ownership are split into fixed and variable costs. These costs represent disutility, which can only be overcome by driving a positive number of kilometres. The form of the utility functions used was derived from statistical analysis of car ownership and use in the Netherlands, and research in the U.S. (de Jong, 1991, Train, 1986). Original research was undertaken to extend the model to cover second cars.

Two models were estimated together: the first model predicts the 0 / 1 car ownership decision, and the second model predicts the 1 / 2 + car ownership decision. The forecast number of licences in the household influences which alternatives are available.

The models are estimated together – and with the model of usage – as they have some terms in common, notably the coefficients of the demand for the first car and the terms involving income and fuel price. The terms in the models are detailed in Table 9.

Table 9: Norway Car Ownership and Usage Model Terms

	Car Ownership Model	
Model Variables	0 / 1 cars	1 / 2 + cars
Log of Remaining Income for 0, 1 or 2 cars	√	√
Variable Cost of Driving	√	√
Log of Household Size	√	√
Age of Head of Household Minus 45, if Aged over 45		√
Age of Head of Household Minus 65, if Aged over 65		√
Female Head of Household	√	
Percent of Population in Built-Up Area	√	√

The output from the model is the number of household cars, and the annual average kilometrage for each car in the household.

For the standard car ownership model component, an LMS-like structure was used. A 0 / 1 cars model was estimated for household with one licence, and a 1 / 2 + cars model was estimated for households with two or more licences. The model terms used in the models are detailed in Table 10.

Table 10: Norway Car Ownership Model Terms

	Car Ownership Model	
Model Variables	0 / 1 cars	1 / 2 + cars
Log of Remaining Income for 0, 1 or 2 cars	√	√
Female Head of Household		√
Female Licenced Driver	√	
Age of Head of Household Minus 45, if Aged over 45	√	√
Age of Head of Household Minus 65, if Aged over 65	√	√
Number of Children (0-17)	√	
Number of Adults (18+)		√
Low Urban Effect Dummy	√	√

4.3.4 Short Distance Travel Models

In the Norwegian model system separate models were used for short-distance and long-distance travel. Short-distance was defined as trips up to 100 km in length, this distance being chosen because of the way in which the data had been collected. Seven journey purposes were modelled for short-distance travel:

- Commuting;
- Home-based (HB) business;
- Work-based (WB) business;
- Education;
- Shopping and services;
- Social visits;
- Other purposes.

Four different modes were modelled:

- Car-Driver;
- Car-Passenger;
- Public Transport;
- Walk / Bike.

Separate tour frequency models were estimated for each journey purpose. The terms used in each of the models are listed in Table 11.

Table 11: Norway Short-Distance Tour Frequency Model Terms

	Tour Purpose						
Model Terms	Work	HB Bus.	WB Bus.	Educ.	Shopping	Social	Other
Full-time Worker	√	√	√	√	√	√	√
Part-time Worker	√	√	√				
Head and Partner Working		√	√	√			√
Female	√	√	√	√	√	√	√
Age under 30				√	√	√	√
Age over 45				√		√	√
Age over 65	√				√		
Car Availability	√	√	√	√	√	√	√
Number of Children < 18 in Household	√	√	√			√	√
Number of Children < 12 in Household				√	√		
High Density Area		√	√	√	√		

The short distance model adopted in Norway did not model destination choice at the zonal level. There were two reasons for this.

1. The network zoning did not contain a sufficient level of detail. The zones used the 454 kommunes in Norway, and the majority of trips less than 100 km have their origin and destination in the same kommune.
2. The destination zones of trips were not given in the one-day trip diary survey data.

To overcome these difficulties, models of mode-*distance* choice were estimated instead, with distance bands used as alternatives instead of specific destinations. Respondents reported the (perceived) distance travelled for each of their trips, so the chosen distance band was known for each observation. Average level-of-service was determined for each of the distance bands. The distance bands used were:

- 0 – 2 km;
- 2 – 5 km;
- 5 – 10 km;
- 10 – 20 km;
- 20 – 35 km;
- 35 – 60 km;
- 60 – 99 km.

The higher proportions of short trips is reflected in the choice of finer distance bands for shorter trips. The variables estimated in the models are listed in Table 12.

Table 12: Norway Short-Distance Mode-Distance Band Model Terms

	Tour Purpose						
Model Terms	Work	HB Bus.	WB Bus.	Educ.	Shopping	Social	Other
CAR-DRIVER:							
Log(cost) / personal income	√	√	√		√	√	√
Travel Time	√	√	√	√	√	√	√
Car Availability	√	√	√	√	√	√	√
Male	√	√	√		√	√	√
Full-time Worker				√	√	√	√
Number of Children < 18	√				√		√
CAR-PASSENGER:							
Time	√	√	√	√	√	√	√
Distance	√	√	√			√	
PUBLIC TRANSPORT :							
Log(cost) / personal income	√	√	√	√	√	√	√
Time	√	√	√	√	√	√	√
Car Availability			√		√	√	√
WALK / BIKE:							
Distance	√	√	√	√	√	√	√
Distance over 4 km	√	√		√	√	√	√
Age under 18	√			√	√	√	√
Age over 45	√				√		√
Male						√	√
High Density				√	√		
ALL MODES:							
Density 0 – 2 km	√		√	√	√	√	√
Density 2 – 5 km	√		√	√	√	√	√
Density 5 – 10 km				√	√		√
Density 10 – 20 km	√	√	√	√		√	
SIZE VARIABLES:							
Total Employment	√	√	√				
Service Employment					√		√
Retail Employment					√		
Student Enrolment				√			
Population						√	√

Note that the cost form in these models differs from the LMS models. In the LMS, log-cost is used, but separate cost terms are estimated for different income bands, reflecting lower cost sensitivity for higher-income travellers. In the Norwegian models, log-cost has been divided by personal income. This approach assumes that the variation in sensitivity to the log of cost is linear with personal income.

4.3.5 Long Distance Travel Models

In the Norwegian model system separate models were used for short-distance and long-distance travel. Long-distance was defined as trips of 100 km and more in length. Five journey purposes were modelled for short-distance travel:

- Work / Education;
- Business;
- Social Visit;
- Recreation;
- Services and Other.

Five modes were modelled:

- Car;
- Bus;
- Train;
- Boat;
- Air.

Note that the purposes and modes in the long-distance model differ from those in the short-distance model, reflecting the different nature of the journeys and modes used.

Separate tour frequency models were estimated for each journey purpose. The terms used in each of the models are listed in Table 13.

Table 13: Norway Long-Distance Tour Frequency Model Terms

	Tour Purpose				
Model Terms	Work / Education	Bus.	Social	Recreation	Services / Other
Full-time Worker	√	√		√	
Part-time Worker			√	√	√
Head and Partner Working					√
Male	√	√	√	√	√
Age 10 - 29	√		√		
Age 30 - 44	√	√	√	√	
Age 45 - 64					√
Car Availability	√	√		√	
Number of Children < 18 in Household	√	√			√
Number of Children < 12 in Household					√
Household Size			√	√	
Personal Income	√	√		√	
Household Income				√	
Low Density Area	√	√	√	√	√
Centrality				√	√
Employment Density				√	
Mode-Destination Logsum	√	√	√	√	√

Note that the long-distance tour frequency models contain accessibility terms, expressed through the mode-destination logsum, which account for higher tour frequency rates from more accessible origin zones.

For long-distance travel, destination choice was modelled using a conventional mode-choice model, using network data defined at the 454 kommune level. The variables estimated in the models are detailed in Table 14.

Table 14: Norway Long-Distance Mode-Destination Choice Models

	Tour Purpose				
Model Terms	Work / Education	Business	Social	Recreation.	Services
TIME AND COST:					
Car Time	√	√	√	√	√
Air Time	√	√	√	√	√
Rail Time	√	√	√	√	√
Boat Time	√	√	√	√	√
Bus Time	√		√	√	√
Access/Egress Time	√	√	√	√	√
Transfer Time	√	√	√	√	√
Car Ferry Frequency	√	√	√	√	√
PT Frequency		√	√	√	√
Log(cost)			√	√	
Log(cost) / personal income		√			
Cost / personal income	√				√
DESTINATION VARIABLES:					
Centrality	√	√	√		√
Population Density			√	√	
Employment Density		√			
SIZE VARIABLES:					
Population			√		
Employment		√			
Hotel Employment				√	
Retail Employment					√
Student Enrolment	√				√

5. PARIS MODEL SYSTEM

5.1 OVERVIEW OF MODEL SYSTEM

The Paris model system was developed by Hague Consulting Group during 1994 and 1995 for the Syndicat de Transports Parisens (STP). The resulting ANTONIN (Analysis of Transport Organisation and New Infrastructure) model system is a travel demand forecasting system for the Ile de France, essentially the enlarged Paris region.

The model system has since been in use by STP in the course of validation and refinement studies, and has been provided externally to a number of planning studies requiring detailed forecasts for the Paris region.

The STP is responsible for the oversight of a wide range of public transport facilities and services covering the region of the Ile de France. The types of public transport services include:

- Metro services providing coverage throughout Paris and nearby communes;
- Bus services covering all of Ile de France and associated bus lanes;
- RER services connecting Paris and the major urbanised regions of Ile de France;
- Rail services connecting Paris and the suburbs;
- Numerous park-and-ride systems located near suburban commuter rail, RER and metro stations;
- Specialised public transport services such as Orly VAL (automated airport connection).

While STP's main focus is on public transport, it is also concerned with the region's road system, since current and future use of public transport is inherently linked with demand for and usage of private cars. Therefore STP required a system capable of forecasting total demand including a wide variety of public transport modes covering a large geographic area.

The system developed by Hague Consulting Group was a disaggregate model system, based upon the structure used in the LMS. However, while the Paris system is multi-modal, it places most emphasis on public transport modes, reflecting the role of the client. The system developed had two key objectives:

1. The capability to evaluate the consequences of the creation or modification of public transport services and facilities, as well as the impact of changes of the highway system on public transport usage;

2. The capability to test a variety of transport policies involving other policy levers and other modes of travel;

3. The ability to provide input to the process of directing revenue from 'though tickets' between public transport operators.

Network changes may involve a large section of the region, or more limited areas at a local level. Both levels of geographic detail can be dealt with within the model system.

Some of the key applications of the model system were for the evaluation of:

- Extension of the region's heavy and light rail systems;

- Modification of the frequency and speed of the region's rail systems;

- Extension of the urban bus system and its reserved bus lanes;

- Modification of fare policies;

- Extension and modification of the region's automobile network.

The model system was designed with these applications in mind.

5.2 MODEL REQUIREMENTS

A number of specific characteristics of the Ile de France market were identified, which influenced the formulation of the analytical methods used for ANTONIN:

1. *Inter modal competition:* In many of the components of the Ile de France market, there is significant competition among two or more travel modes. Depending on the area and type of trip, this competition is primarily among transport modes or between car and public transport.

2. *Multiple paths within modes:* A review of network data suggested that, in many areas, both automobile and public transport users have multiple alternative paths that provide reasonable service levels. The competition between the various routes is particularly strong in the case of public transport, where differences in perceptions of the characteristics of the various routes and technologies (bus, tram, metro, RER) may require detailed analysis;

3. *Importance of access modes:* Many of the existing public transport users take several modes or lines in order to reach their final destination. For example, someone may take the bus to reach the metro and then walk to their final destination. The manner in which the sequencing of trip stages is treated can have a significant impact on the viability of the forecasting models since travellers are presented with several alternative public transport paths in many instances.

4. *Capacity limitations:* Nearly all of the major roadways and public transport facilities operate at or near capacity during the peak periods. The impact of this fact on mode and path choice needed to be considered.

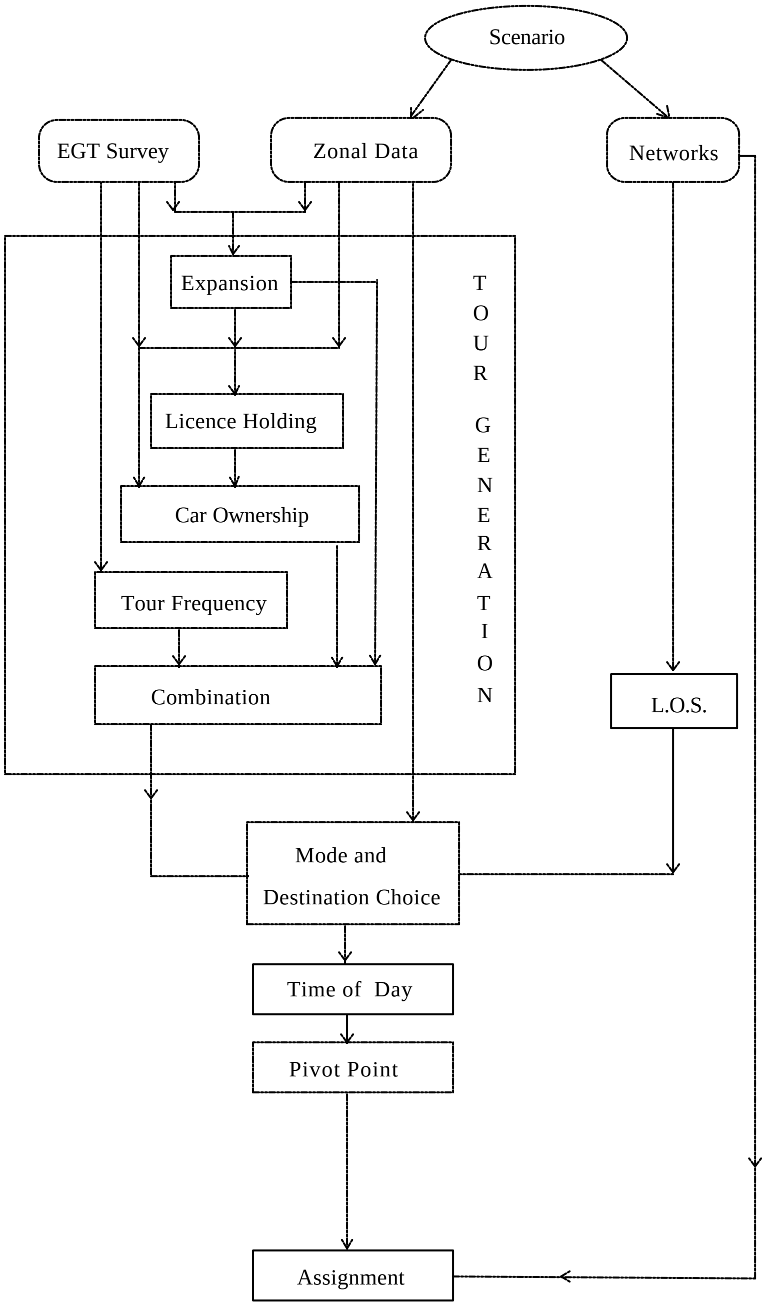
5. *Peak spreading:* One of the trends in the Ile de France is the lengthening of both peak periods in response to the saturation conditions that exist in the heart of the peaks. This trend mitigates deterioration in service to some extent, an effect that is rarely included in traditional travel demand forecasting methods, although it is a feature of, for example, the LMS.

6. *Representation of walk and automobile access:* The forecasting models are used primarily to forecast demand (or changes in demand) on specific links of the public transport system. Choice of mode and destination path is very strongly influenced by the quality and time of access to the mode. Therefore the best possible representation of access to the PT services was necessary, using a zonal split as fine as possible to reproduce as closely as possible the variety of access conditions facing travellers in each zone.

5.3 MODEL STRUCTURE

The model structure adopted for the ANTONIN model system is based on the LMS structure. The structure is illustrated in Figure 10.

Figure 10: ANTONIN Model Structure



5.3.1 Model Inputs

The model inputs for a given scenario run are:

- Zonal data. This file consists of attraction variables for the mode-destination models, such as total employment by zone, zonal targets for the prototypical sample procedure and parking costs in each destination zone;
- LOS matrices. These matrices are built using separate modules for car and walk, and for public transport modes.

5.3.2 Model Outputs

The final model output is matrices of trips split by mode, purpose and time-of-day which are then assigned. Matrices are determined for 13 different modes:

1. Car Driver;
2. Car Passenger;
3. Two Wheeled Modes and Walk;
4. Rail;
5. Metro;
6. Bus;
7. Rail-Metro;
8. Rail-Bus;
9. Metro-Bus;
10. Rail-Metro-Bus;
11. Car-Rail;

12. Car-Bus;

13. Car-Rail-Metro.

Note that the number of modes is higher than in any of the other model systems described in this report. This is a consequence of the complex treatment of PT modes, a reflection of the needs of the client.

The matrices are also split by 10 tour purposes:

1. Commute – white collar;
2. Commute – blue collar;
3. Business;
4. Education for school children;
5. Education for students;
6. Daily/weekly/fortnightly shopping;
7. Other shopping;
8. Social, recreational and all other home-based;
9. Work-based business;
10. Work-based other.

An interesting feature of the ANTONIN model system is the split between daily/weekly/fortnightly shopping, which would include essential food shopping, and less frequent shopping trips, such as shopping for luxury items or furniture. As well as the obvious difference in tour frequency, the mode-destination characteristics of the shopping types vary, with 'other shopping' locations tending to be more distant, and less likely to be accessed using slow modes.

The ANTONIN model system is comprehensive in its treatment of work-based travel in that all possible purposes are modelled. This means for example that tours to a cafe outside the workplace for lunch are modelled.

The matrices are split by four times of day:

1. Morning peak;
2. Midday;
3. Evening peak;
4. Night time.

5.4 MODEL COMPONENTS

5.4.1 Prototypical Sample

The prototypical sample consists of 9,835 households containing 22,421 individuals drawn from the 1991 Transport Survey in Ile de France. The expansion factors are derived from the 1990 census.

The prototypical sample contains the following household information:

- Residence zone;
- Number of persons;
- Number of adults (aged 18 plus);
- Number of infants (aged up to six);
- Number of children (aged six to 18);
- Number of workers;
- Number of licences;

- Number of available cars;
- Income.

The prototypical sample contains the following person information:

- Age;
- Sex;
- Position in the household (head / partner / other);
- Main occupation;
- Licence holding;
- Level of education.

This household and personal information is sufficient to apply all the disaggregate models in the ANTONIN system.

The households in the prototypical sample are split into three household categories:

- Age of head of household: under 40, 40 to 65, 65 +;
- Household size: 1, 2, 3, 4, 5 + persons of working age;
- Sex of worker: no workers, one male worker, one female worker, two plus workers.

In total 60 household categories are possible.

5.4.2 Licence Holding Models

The disaggregate models of licence holding use the same structure as the models in the LMS, described in Section 3.3.2. The main model predicts the licence holding for the head of the household and their partner, if one exists. A sub-model is used to predict the licence holding of any other adults in the household.

The model terms in the licence holding model are as follows:

Table 15: ANTONIN Head and Partner Licence Holding Model Terms

	Model Alternative			
Model Variables	No Licence	Head Holds Licence	Partner Holds Licence	Both Adults Hold Licences
Age over 65		√		√
Gender		√		√
Full Time Worker		√	√	√√
Higher Education		√	√	√√
Resident in Paris		√	√	√√
Resident in de Grande Couronne		√	√	√√
Household Income	√			√

The model for other adults in the household contains similar terms to those presented in Table 15.

An aggregate cohort licence projection model is used to forecast total licence holding, and corrections are made to the weighted disaggregate forecasts as necessary. The cohorts used in the ANTONIN system contain a higher level of age segmentation than the other model systems presented in this report, with the following age bands used:

- 15 – 19;
- 20 – 24;
- 25 – 29;
- 30 – 34;
- 35 – 39;
- 40 – 44;
- 45 – 49;
- 50 – 54;

- 55 – 59;
- 60 – 64;
- 65 – 69;
- 70 – 74;
- 75 – 79;
- 80 – 84;
- 85 +.

5.4.3 Car Ownership Models

The car ownership model is run after the licence holding models, and the alternatives available are dependent on the outcome of licence models, as illustrated in Figure 11.

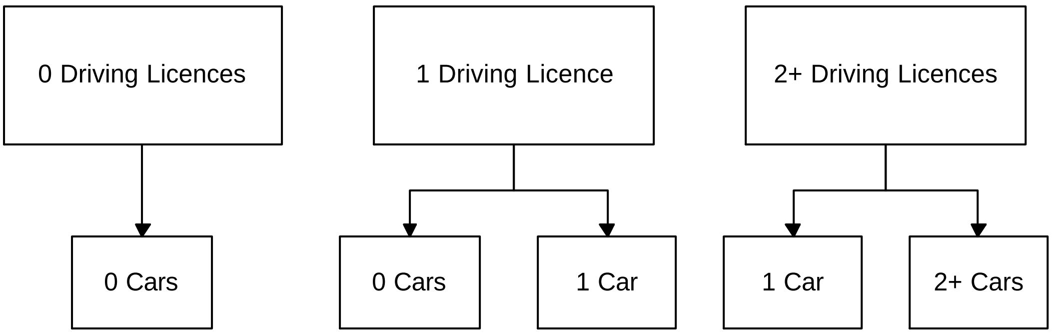


Figure 11: ANTONIN Car Ownership Model Alternatives

This is the same structure as the LMS. The model terms are summarised in Table 16.

Table 16: ANTONIN Car Ownership Model Terms

	Car Ownership Model	
Model Variables	0 / 1 cars	1 / 2 + cars
Gender	√	√
Higher Education	√	
Age of Head over 65	√	√
Residence Zone in Paris	√	√
Residence Zone in Grande Couronne	√	√
Two Plus Workers	√	
Number of Workers		√
Number of Children Under 12	√	√
Number of Adults		√
Log of Disposable Income	√	√
Cost of Parking	√	√

Zone of residence was a highly important variable in the models. Central Paris has large numbers of apartment blocks, and consequently high residential densities, and in such areas lack of parking is a negative factor counting against car ownership. The cost of parking term also accounts for this effect.

5.4.4 Tour Frequency Models

The tour frequency models used in the ANTONIN model system uses the same structure as the models used in the LMS, detailed in Section 3.3.4.

The terms in the 0 / 1 + model are detailed in Table 17.

Table 17: ANTONIN 0 / 1 + Tour Frequency Model Terms

	Tour Purpose									
Model Terms	Com. High	Com. Low	Bus.	Sch.	Oth. Edu.	Reg. Shop.	Oth. Shop.	Social	Work Bus.	Work Oth
Gender		√	√			√		√	√	√
Age Terms	√	√			√	√	√	√	√	√
Full Time Worker		√				√	√	√		√
Part Time Worker	√	√	√			√	√	√	√	
Student						√		√		
Licence							√	√	√	
Higher Education					√	√	√	√		
Paris Residence	√		√	√			√			√
GC Residence	√		√						√	
Car Availability			√				√	√	√	
Hhld. Income				√		√	√		√	√
Working Adults		√	√		√					
No. of Adults					√	√		√		√
No. Children Aged Under 6					√					√
No Children		√		√						

Note that GC denotes the Grand Couronne region.

The terms in the stop / go model are similar to those in the 0 / 1 + model.

5.4.5 Mode-Destination Models

Mode-destination models have been estimated for each of the 10 purposes detailed in Section 5.3.2. The terms used in the models varies by purpose, as detailed in Table 18.

Table 18: ANTONIN Mode-Destination Model Terms

	Tour Purpose									
Model Terms	Com. High	Com. Low	Bus.	Sch.	Oth. Edu.	Reg. Shop.	Oth. Shop.	Social	Work Bus.	Work Oth
Intra Dummy	√	√	√	√	√	√	√	√	√	√
Car Comp CarD	√	√	√	√	√	√	√	√	√	√
Car Comp CarP	√	√	√	√	√	√	√	√	√	√
Car Time	√	√	√	√	√	√	√	√	√	√
Log Cost	√	√	√	√	√	√	√	√	√	√
Car Pass. Time	√	√	√	√	√	√	√	√	√	√
Licence	√	√	√	√	√	√	√	√	√	√
Two+ HH Lics.				√		√	√	√		
Walk Distance	√	√	√	√	√	√	√	√	√	√
PT In Veh.Time	√	√	√	√	√	√	√	√	√	√
Acc./Eg. Time	√	√	√	√	√	√	√	√	√	√
Wait Time	√	√	√	√	√	√	√	√	√	√
Interchanges	√	√	√	√	√	√	√	√	√	√
Employment in Dest. Zone	√	√	√				√		√	
Retail Emp. In Dest. Zone							√			√
Population in Dest. Zone		√	√	√		√	√	√		√
Student Places in Dest. Zone					√					
Local Food Store Emp.						√	√	√		√
Employment Dens. Car-Driv.	√									
Employment Dens. PT	√	√			√	√	√			
Population Dens. CarD						√				
Population Dens. CarP						√				
Population Dens. PT						√				
Paris Dummies	√	√	√	√	√	√	√	√	√	√
PC Dummies	√	√	√	√	√	√	√	√	√	√
GC Dummies	√	√	√	√	√	√	√	√	√	√
Other Region Dummies	√	√	√	√	√	√	√		√	

Note that PC denotes the Petit Couronne region, and GC denotes the Grand Couronne region. These dummies are either origin or destination based or both, and some are mode-specific, and so they account for underlying variations in mode-destination preferences between regions not accounted for by other model terms.

It can be seen from Table 18 that the level-of-service terms are the same for all purposes, and variation between model purpose is in the specification of the attraction variables in the destination zone, other destination terms such as employment density, and regional dummies.

The two plus household licences terms accounts for higher car-passenger availability in higher licence holding households, which is important for education, shopping and social/other.

6. COPENHAGEN MODEL SYSTEM (OTM)

6.1 OVERVIEW OF MODEL SYSTEM

The Ørestad Traffic Model (OTM) was originally developed in 1994 by Hague Consulting Group, working in collaboration with TetraPlan Ltd of Copenhagen, Denmark. The model system was updated in 1996 and 1998, and in 2000 was extensively revised with a switch from the trip to the tour based modelling approach.

The OTM was originally developed to predict the demand levels for a new metro system, which will begin the first phase of its operation in the autumn of 2002. The OTM has also been used for detailed planning of bus services in the Copenhagen region, and has recently been applied for a study of road pricing.

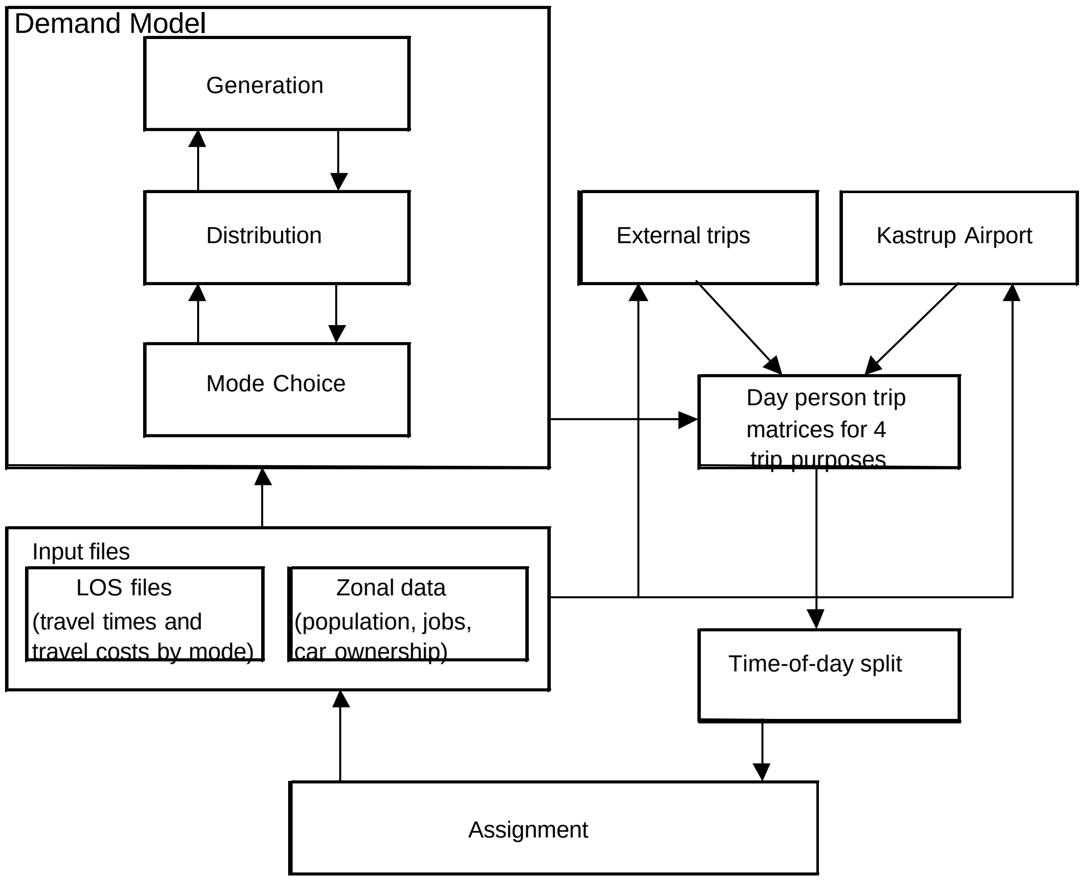
There are three key differences between the OTM model system and the other model systems presented in this report. Firstly stated preference (SP) data was been used in model estimation, to model the new metro alternative, and also to calibrate values-of-time. Secondly the distribution component of the model is *aggregate* in nature. The generation and mode-choice models used in the OTM are disaggregate, however. Thirdly the OTM is a short-term forecasting model, whereas the other model systems generally have medium to long-term forecasting horizons.

In the OTM model system, there are no licence holding or car ownership models. In a short-term forecasting system there is less need to forecast these medium to long term decisions; rather observed licence holding and car ownership can be used.

6.2 MODEL STRUCTURE

The structure of the OTM model system is summarised in Figure 12.

Figure 12: OTM Model Structure



The key model components together form the demand model, which comprises a nested logit structure where the generation, distribution and mode-choice models are inter-connected via logsums.

External trips are predicted using a separate model component, as are trips to and from Copenhagen Kastrup airport. Freight trips are predicted using an entirely separate model system, and added at the assignment stage.

6.2.1 Model Inputs

The model inputs for a given scenario run are:

- LOS files defining travel times and costs by mode – these files will reflect any changes in infrastructure or pricing policy being evaluated;

- Zonal data – population, jobs, car ownership etc. by zone – these files will reflect forecast changes in zonal characteristics.

There are a total of 601 zones in the OTM model system, and 17 external 'port' zones.

6.2.2 Model Outputs

The final model is output is matrices of trips split by time-of-day and mode, ready for assignment. Matrices are determined by the following modes:

- Car-driver;
- Car-passenger;
- Bus;
- Train;
- Walk;
- Bike;
- Light-rail.

Three time periods (AM peak, PM peak, off-peak) are used in assignment.

6.3 MODEL COMPONENTS

6.3.1 Generation Models

The tour generation models are disaggregate models, which determine the probability of an individual making a tour for a given purpose during a given time period. Four separate tour purposes are modelled:

- Business;
- Commuter;
- Education;
- Leisure.

The tour frequency depends on the following personal and household variables:

- Employment 'level' (higher, middle or lower level, self-employed, student, retired, not-employed);
- Number of cars per person in a household.

In the leisure segment, an accessibility term has been estimated. This term accounts for short-term induced traffic due to any improvements in infrastructure, and consequent changes in accessibility. The lack of similar terms in the generation models for the other purposes implicitly implies that improvements in infrastructure will not generate additional business, work or education tours *over the short term*.

The manner in which the tour generation models are applied in the OTM differs from the other model systems because the subsequent distribution model is applied at the aggregate level. Consequently the generation model is also applied at the zonal level. A *pivot-point* procedure is used, where the predicted number of tours per zone is calculated as a multiple of an observed tour matrix:

$$T_i^x = M * (\text{Predicted } T_{ri}^x / \text{Predicted } T_{ri}^{92})$$

where: M is the observed number of tours in zone i in the base year

Predicted T_{ri}^x is the predicted number of tours in the scenario

Predicted T_{ri}^{92} is the predicted number of tours in the base year

Special rules are used when one or more of the terms take values of zero.

6.3.2 Distribution Models

The model is calibrated using 1992 observed base matrices. Utility functions for a given origin are defined for each destination, using the following terms:

- Non-linear distance terms;
- Intrazonal dummies;
- Zonal attractions;
- Mode-choice logsums, reflecting the accessibility between origin and destination zones.

The zonal attractions used vary according to purpose:

- Business: number of trips to destination zone;
- Commute: number of jobs in destination zone;
- Education: number of study places in destination zone;
- Leisure: number of jobs in service and retail categories.

The distribution model is also applied using a pivot-point procedure. This is done by adding correction terms into the utilities, which minimise the difference between the observed and predicted tour matrices in the base year. Note that in the base year, the total trips originating and with destination in each zone are the same in the observed and predicted matrices, but individual cell-values predicted by the distribution model can differ from the observed matrix.

6.3.3 Mode Choice Models

The mode choice model was estimated from a combination of Revealed Preference (RP) and Stated Preference (SP) data. SP data was used for two reasons:

- To model the new metro alternative, which is not an available mode at present;
- To calibrate values of time, which vary by mode and purpose.

The procedure used to estimate the mode choice model from a combination of RP and SP data is essentially that summary RP data is used to calibrate the mode specific constants to current market volumes, and SP data is used to assess the propensity of travellers to switch to the new alternative, in this case metro.[5] More information on this procedure is available in Daly and Rohr (1998), detailed in the References section.

A separate mode-choice model was estimated for each model purpose. The models include the following terms:

- Cost;
- Access/egress times;
- Waiting time;
- Interchange terms;
- Car time terms (free-flow and congested separately);
- Parking time – time to locate a parking place;

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[5] In the latest version of the OTM, SP and RP data is also used from two other studies: the Harbour Tunnel (a road scheme) and Copenhagen-Ringsted (heavy rail) studies. The data base is therefore quite complicated.

- Walk / bike time;
- Train in-vehicle time;
- Metro in-vehicle time;
- Bus in-vehicle time;
- Peak / off-peak travel dummies;
- Seating layout terms for PT.

The models also include a number of correction terms from the procedures used to implement the models.

6.3.4 External Traffic Model

External through trips (i.e. trips between the port-zones) and trips with one leg in port-zones are modelled in the external model. This models 15 of the 17 port-zones – the other two are modelled using a separate model, briefly described in the following section.

The base-year port-zone trips are determined from traffic counts, and the distribution of trips within the greater Copenhagen area is estimated using matrix adjustment procedures.

The forecast number of port-zone trips is based on other models, regression analyses or matrix adjustment procedures. The OTM allows flexibility in the calculation of external trips.

6.3.5 Kastrup Airport Mode-Choice Model

This model uses the results of an SP survey conducted at the domestic and international terminals of Kastrup airport during 1998. A total of 150 interviews were undertaken.

Only two modes were modelled, bus and train, and only two purposes, business and leisure.

7. STOCKHOLM MODEL SYSTEM

7.1 MODEL OVERVIEW

The Stockholm Integrated Model System (SIMS) was developed by Hague Consulting Group working in collaboration with the Development Department at Stockholm Transport and the County Council Public Transport office. The model system is based on a travel survey undertaken in 1986 and 1987, but implementation was only completed in 1995.

The large delay between collecting the data and final model implementation was as a result of extensive discussions as to the form of the disaggregate models to be used. However, as a result of these discussions the model forms adopted are the most advanced presented in this report, as will be seen from Section 7.3, and have structures which are quite distinct from the LMS system detailed in Chapter 3. The detour modelling in SIMS is extensive, covering non-work purposes, and as such the model system provides a highly comprehensive representation of travel patterns.

At the time of development of the model system, a range of important transportation issues were under consideration:

- Area licensing;
- Introduction of new trams;
- Construction of new ring roads.

Travel demand forecasting models were required which allowed the evaluation of a wide range of policies with respect to the economic, environmental and other criteria required by the local authorities. The need to evaluate specific policies necessitated a high level of geographical detail.

A particular consideration in the development of the SIMS was the high level of female participation in the work force in Stockholm. This had implications in the structure of the work model, where car allocation between the head of the household and their partner was explicitly modelled[6], and in the shopping model, were shopping trips were modelled as being made by groups of one or more persons from the household.

The structures adopted for the work and shopping models are quite distinct, and differ considerably from the other model systems presented in this report. The structures for the other model purposes are generally simpler in structure. The model structures represent household behaviour in terms of *choice under constraint*, and consequently the model structures adopted have a higher degree of interaction between the constituent sub-models than most model systems.

The SIMS model differs from the other model systems presented in this report in a number of ways. Firstly there is considerable variation in the ordering of the individual choices between different model purposes, so that for work tour frequency is modelled beneath destination choice, whereas for shopping tour frequency is modelled above destination choice. The SIMS system models car allocation amongst household members, an advance feature not present in the other model systems reviewed. Finally, the shopping model (more realistically) considers tour frequency at the household level. The other model systems all model frequency at the person level.

The SIMS system does not model licence holding. Although licence holding is already high in Stockholm, and so changes relative to the base year are likely to be smaller than for example in Sydney, this is a disadvantage of the SIMS system, particularly over the longer term.

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6 Where a partner exists, of course.

7.2 MODEL STRUCTURE

Six model purposes have been modelled in the SIMS:

1. Work;
2. Business;
3. School;
4. Shopping;
5. Social;
6. Other.

Five modes are modelled:

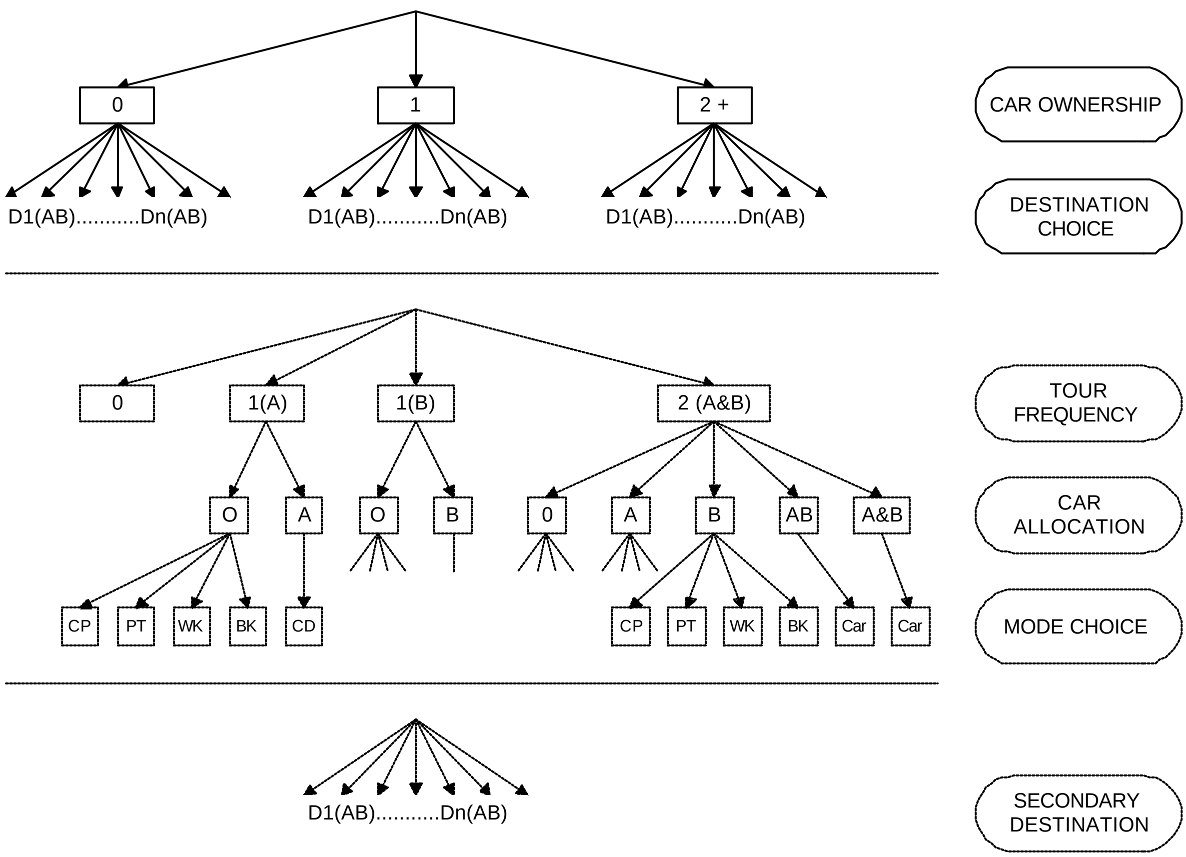
1. Car-Driver;
2. Car-Passenger;
3. Public Transport;
4. Walk;
5. Cycle.

The model system uses 850 zones.

7.2.1 Work Travel

The work trip component of the model system is illustrated in Figure 13.

Figure 13: SIMS Work Model



Given the complexity of the work model system, the structure was too complicated to estimate in one step (with the computer software and hardware of the time), and so was been split into substructures, denoted by dotted lines.

Each of the substructures was estimated separately.

Figure 13 shows the choices available to a household with two working members. If a household has only one member, then the complexity is reduced considerably. If a household has more than two working members, then the two main workers are identified, and the other workers are treated separately as special one-person households. The main workers are labelled A and B, and the coding used means A is usually male and B is usually female.

The first model in the decision hierarchy is the car ownership model, which is a medium to long term household decision. Next is the *simultaneous* choice of workplace destination for the two main workers in the household, dependent on car ownership. An accessibility measure from lower down the structure accounts for increased attractiveness of more accessible work destinations.

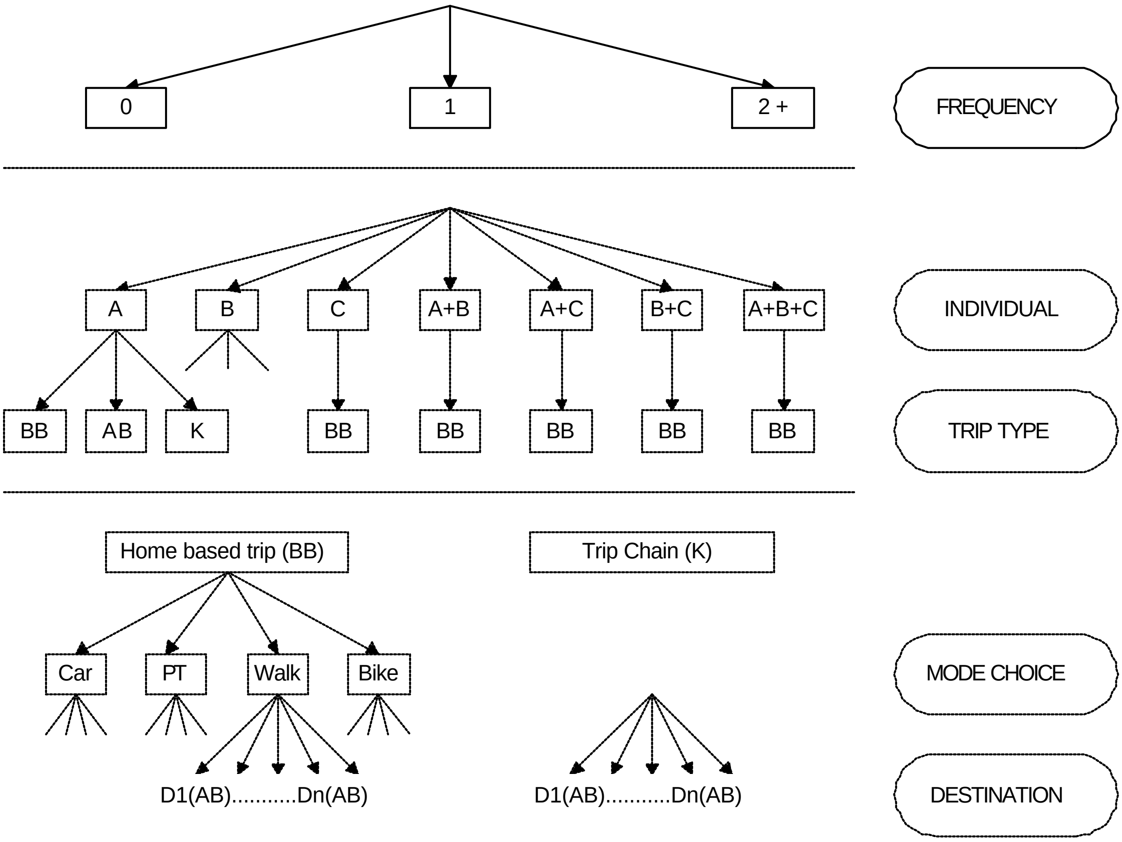
The middle substructure consists of models of trip frequency, car allocation amongst the household, and mode choice. The three models are estimated simultaneously. In the trip frequency model, each possible combination of work trip making is considered, and so one possible outcome it that no work tours are predicted. It is assumed only one home-based work tour is made per day. In the car allocation procedure the alternatives available are dependent on the outcome of the car ownership model. The alternative AB denotes A and B going to work in the same car, and A&B denotes both going to work by two separate cars (available when two cars are owned).

The final model in the structure is a model of secondary destination, which is modelled as a choice as to whether or not to chain to a second trip purpose, and if so to what destination. As the mode has already been defined, separate secondary destination models are defined for each mode. The modes considered are car and public transport; slow modes are not considered.

7.2.2 Shopping Travel

The work trip component of the model system is illustrated in Figure 14.

Figure 14: SIMS Shopping Model



The same model structure is used for two different types of shopping: MD (minor daily shopping) and OS (other shopping). The MD category has much shorter trip distance, and higher trip frequency, than the OS category.

The first model in the structure is the frequency model. The other model systems in this report model shopping trip frequency as a personal decision, but here the number of shopping tours made per day by the *household* is modelled. Considering shopping frequency as a household decision is probably a more realistic approach, but is difficult to implement in more conventional model systems.

The second structure allocates the household shopping trips to individuals and a trip type. The household is divided into persons A (often male), B (often female) and C (other persons aged 12 and above). Various combinations of these person types gives up to seven alternatives to which shopping trips can be allocated.

The different trip types considered are home-based tour (BB), work based tour (AB) and work trip detour (K). When the individuals travel as a party, and for 'C adults', only home-based tours are modelled.

The mode and destination choice models consider mode choice above destination, the same structure used in the Sydney shopping models, implying destination choice is more elastic than mode choice. However, in SIMS the choice unit is not the individual but the group of individuals making the trip.

Chains of shopping trips to multiple shopping destinations are modelled.

7.2.3 Other Travel Purposes

The model structures adopted for the other travel purposes (business, school, social, other) are more straightforward.

For business trips, choice of trip chain, choice of mode and choice of destination are included in the logit structure.

For school trips, only mode and destination choice are considered.

Social trips use a different structure for home-based and chained trips. For home-based social trips, trip frequency, mode and destination choice are included in the structure. For chained social trips, frequency and destination choice are included, as mode is dependent on the mode of the work trip.

For the other trip purposes, the structure is the same as the shopping structure, detailed in Figure 14.

8. SYDNEY MODEL SYSTEM (STM)

8.1 MODEL OVERVIEW

The Sydney model system was developed between 1999 and 2001 by Hague Consulting Group, working in collaboration with Institute of Transport Studies of the University of Sydney and Monash University, for the Transport Data Centre at the New South Wales Department of Transport in Sydney, Australia. The model system is referred to as the Strategic Transport Model (STM).

TDC seeks to service the needs of both government and private transport sectors through the provision of high quality and timely data and modelling services, and the STM is a key tool in achieving this objective.

The STM was originally developed in the 1970's, and had come to be regarded as inappropriate for the analysis of current transport policy and planning issues. As a result, a full design project, followed by two stages of extensive enhancements have been commissioned, all of which have been undertaken by HCG. A third stage of enhancements to the STM system may also be commissioned.

In formulating the recent enhancements to the STM, a number of *stakeholders* were identified. The stakeholders were consulted in order to identify key policy agendas and how they could be assisted by outputs of models. The stakeholders are:

- NSW Department of Transport;
- NSW Treasury;
- Ministry of Urban Infrastructure Management;
- CityRail;
- Rail Access Corporation;

- State Transit Authority;
- Roads and Traffic Authority;
- The Environmental Protection Authority;
- Department of Urban Affairs and Planning.

The enhancements made to the STM were planned and undertaken with the needs of all of the stakeholders in mind.

In the Stage 1 enhancements, disaggregate models of licence holding, car ownership, home-work tour frequency and home-work mode-destination choice were estimated and implemented. A model system capable of forecasting home-work travel on an average workday was delivered to TDC.

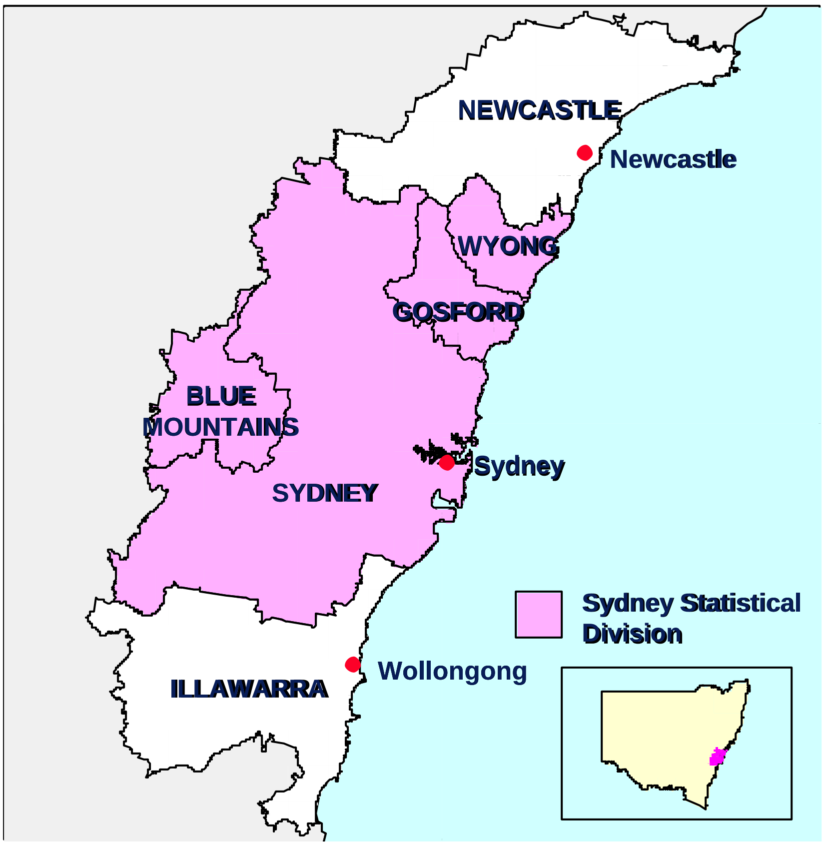
In the Stage 2, enhancements, home-based models of tour frequency and mode-destination choice have been estimated and implemented for home-business, home-education, home-shopping and home-other travel have been estimated and implemented. Furthermore, two non-home-based (NHB) business tour frequency and mode-destination models have been estimated and implemented: a work-based business tour model, and a business *detour* model, which models detours to work or business destinations.

The STM model system is disaggregate throughout, and the unit of travel is the tour. An advanced feature of the STM is the business detour model, which accounts for the scheduling, and relative importance, of different activities. The detour model models detours to secondary business destinations, both on the outward journey to the primary destination, and on the return to home. The primary and secondary destinations are identified according to certain hierarchical rules.

At present only business detours are modelled, but the system could be extended to model detours to other destinations, for example dropping children at school on the way to work. Such an improvement would results in a highly comprehensive and detailed representation of daily travel patterns.

The model study area is illustrated in Pink in Figure 15.

Figure 15: Sydney STM Study Area



8.2 MODEL STRUCTURE

The STM comprises two key components:

- The 'Population Model' which contains the prototypical sampling procedure, the licence cohort projection module, and the disaggregate models of licence holding and car ownership. A single Population Model feeds into the models for each tour purpose.

- 'Travel Demand Models' (TRAVDEMs) which apply the car availability adjustment, tour frequency and mode destination models and then factors the output to obtain matrices split by time-of-day. Separate TRAVDEMS exist for each tour purpose.

These two components are illustrated in the following two figures.

Figure 16: STM Population Model Structure

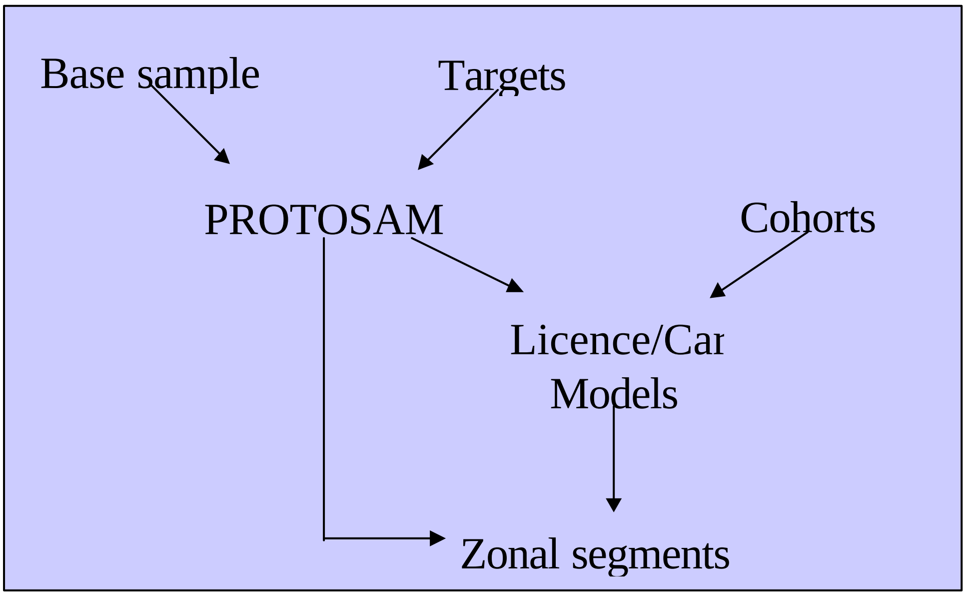
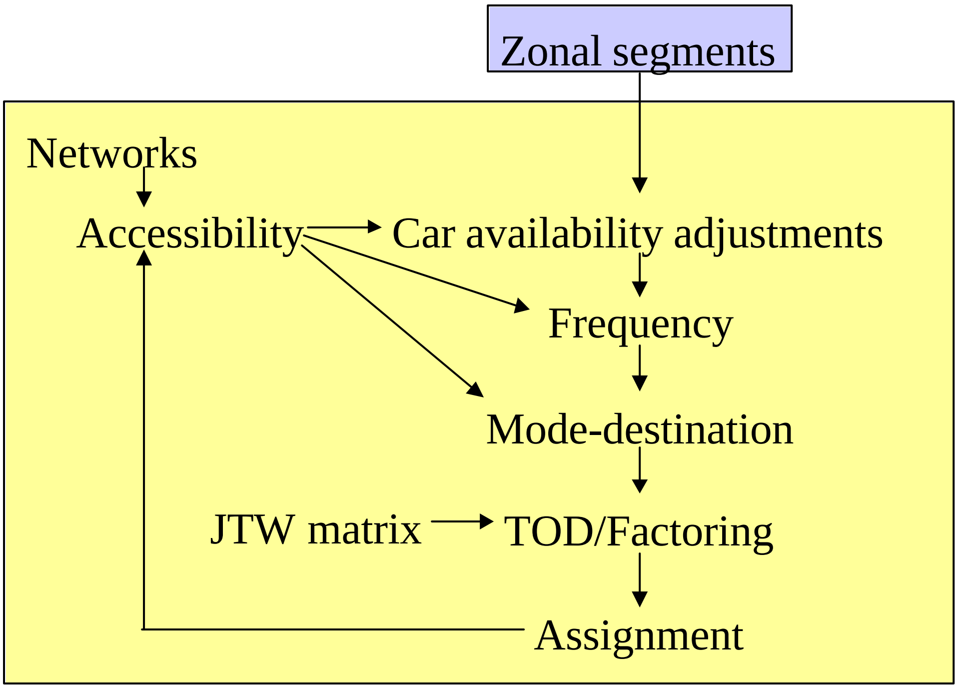


Figure 17: STM Travel Demand Model Structure



Three advanced features of the STM should be noted:

1. The travel demand module is inherently iterative in operation, because the accessibility has to be derived in part from a traffic assignment, which in turn depends on the level of travel demand. Thus the system iterates between assignment and the demand forecasting model.

2. A car availability module is used, which accounts for changes in total car ownership due to changes in accessibility. Higher total car ownership is forecast from more accessible origin zones.

3. Accessibility impacts upon the tour frequency models, so that higher tour rates are predicted from more accessibly origin zones.

8.2.1 Model Inputs

The inputs to the TRAVDEM models are:

- Network files for car (all periods of the day) and public transport (AM peak only). The public transport files are provided separately for the complete public transport system and the bus network alone.

- Zonal files giving attraction variables and parking costs.

- The JTW matrix which gives an observed base matrix of home-work tours, obtained from the 1996 census, split by mode.

- The zonal segments file produced by the Population Forecasting Model.

8.2.2 Model Outputs

The outputs from the model are trip matrices split by mode, purpose and time-of-day.

Nine separate purposes are modelled:

1. Home-Work;

2. Home-Business;

3. Home-Primary Education;

4. Home-Secondary Education;

5. Home-Tertiary Education;

6. Home-Shopping;

7. Home-Other;

8. Work-Business;

9. Business Detour.

Seven modes are modelled:

- Car-Driver;
- Car-Passenger;
- Train;
- Bus[7];
- Bike;
- Walk;
- Taxi.

Four times-of-day are modelled:

- AM Peak;

7 Split into school-bus and non-school bus for primary and secondary education.

- Inter-Peak;
- PM-Peak;
- Evening / night.

8.3 MODEL COMPONENTS

8.3.1 Prototypical Sample

The prototypical sample is a sample of 7,499 households containing 20,144 people, drawn from the Household Travel Survey (HTS), and containing data collected between 1997 and 2000. The sample contains sufficient household and person information to apply the disaggregate models of licence holding, car-ownership, tour frequency and mode-destination choice described in the following sections. The households in the prototypical sample are split into 74 household categories:

- Four number of adults categories: 1, 2, 3, 4+;
- Five number of workers categories: 0, 1, 2, 3, 4+;
- Two presence of children categories: yes/no;
- Four age of person with highest income categories: < 30, 30-45, 45-65, > 65.

Note that only certain combinations of these categories are possible. Care has been taken to ensure that there are sufficient households in each category to make statistically significant statements about the travel behaviour of each category.

The prototypical sample is then applied in a similar fashion to the LMS sample, described in Section 3.3.1.

8.3.2 Licence Holding Models

The disaggregate models of licence holding use the same structure as the models in the LMS, described in Section 3.3.2. The main model predicts the licence holding for the head of the household and their partner, if they exist. A sub-model is used to predict the licence holding of any other adults in the household.

The model terms in the licence holding model for the head and partner are as follows:

Table 19: STM Head and Partner Licence Holding Model Terms

	Model Alternative			
Model Variables	No Licence	Head Holds Licence	Partner Holds Licence	Both Adults Hold Licences
Household Income		√	√	√√
Female		√	√	√√
Full-Time Employed		√	√	√√
Male, over 70 Years		√		√
Female, over 50 Years			√	√
Female, over 70 Years			√	√
Number of Children	√			√
Number of Adults	√			√

The model for other adults contains similar terms to the head and partner model, together with terms which explicitly depend on the outcome of the head and partner model.

The weighted predictions from the disaggregate licence holding model are adjusted to match the aggregate projections from a cohort model. This model uses cohorts split by gender and age (four bands). In Sydney, the high rate of immigration by people whose licence holding differs from native Australians impacts has an important effect on licence holding patterns. Specifically, female immigrants have much lower licence holding rates than native female Australians. The cohort model models the effect of migrants explicitly.

8.3.3 Car Ownership Models

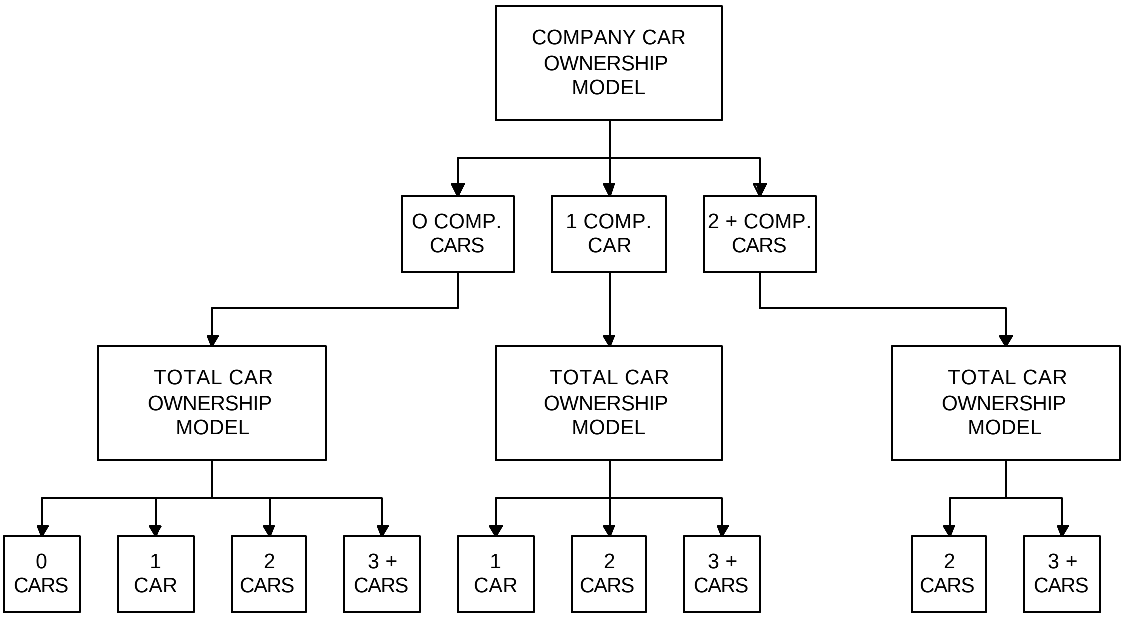
The disaggregate models of car ownership used in Sydney explicitly model the company car ownership of the household. Model tests were undertaken to determine whether:

- Private and company car ownership decisions are independent;
- Private car ownership depends on company car ownership;

- Company car ownership depends on private car ownership.

Model tests revealed a structure that first predicts the holding of company cars in the household, and then uses a second model to predict the total numbers of cars owned.

Figure 18: STM Car Ownership Model Structure



It can be seen from Figure 18 that the alternatives available in the total car ownership model are dependent on the outcome of the company car ownership model.

The company car ownership model contains the following variables.

Table 20: STM Company Car Ownership Model Variables

Variables	Car-owning Alternatives	
	1 Company Car	2 + Company Cars
Net household income ($000/year, 1996 prices)	√	√
Female head of household	√	√
Head of household over 35 years	√	√
Head of household over 50 years	√	√
Head of household under 29 years	√	√
Cost of Parking	√	√
Number of adults without licences	√	√
Less than two workers with licences		√

Note that the log of household income was found to give a better fit than a linear form.

The total car ownership model contains the following variables:

Table 21: STM Total Car Ownership Model Variables

Variables	Alternatives			
	No Car	1 Car	2 Cars	3+ Cars
Net household income ($000/year, 1996 prices)		√	√	√
Female head of household		√	√	√
Head of household over 35 years		√	√	√
Head of household over 50 years		√	√	√
Head of household under 25 years		√	√	√
Number of full time workers		√	√	√
Number of part time workers		√	√	√
Number of children in household		√	√	√
Number of licences in household		√	√	√
Number of unlicensed adults in household		√	√	√
Licences less than cars			√	√
Parking cost		√	√	√
1 company car in household*			√	√
2+ company cars in household*				√
Accessibility term	√	√	√	√

The terms marked with an asterisk (*) depend directly on the results of the company car model.

Note that the total car ownership model contains an accessibility term, which accounts for higher total car ownership in more accessible origin zones.

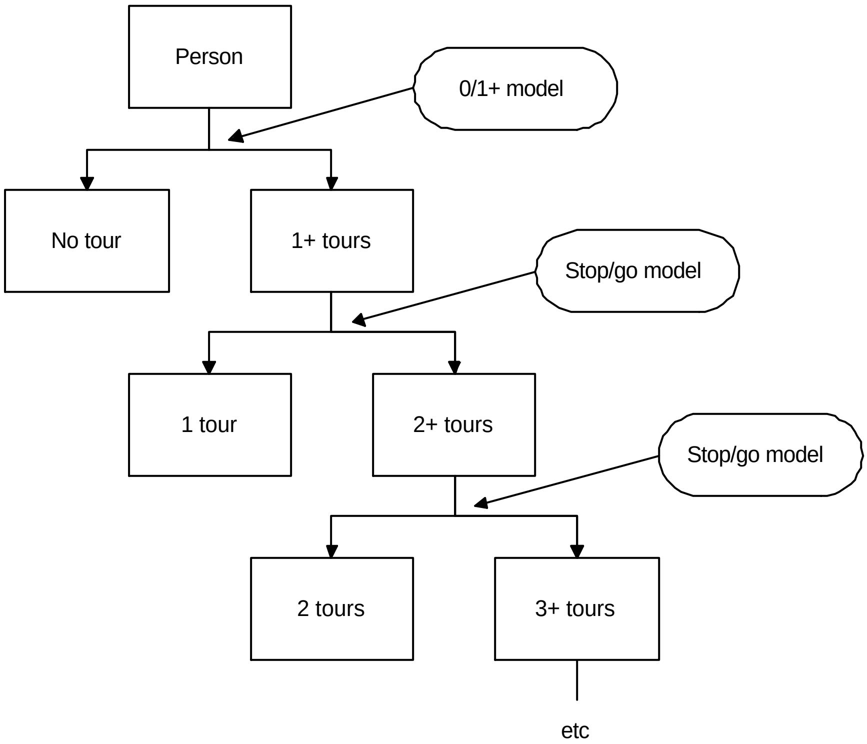
Both the company and total car ownership models use 'net' household income, which in this context is calculated as gross household income minus the ownership costs for the number of *private* vehicles in the household. This is the approach used in the LMS car ownership models.

The disaggregate models of car ownership are expanded to give the weighted car ownership in the prototypical sample. In the LMS the total car ownership forecasts are adjusted to match aggregate forecasts. This is not the case in the STM, in which the car ownership models were estimated on repeated cross-section data over a considerable period (1991-99).

8.3.4 Tour Frequency Model

The tour frequency models predict the numbers of tours made per person per day for a specific journey purpose. Separate tour frequency models have been estimated for each of the tour purposes listed in Section 8.2.2. The structure used for all the *tour* frequency models is illustrated in Figure 19.

Figure 19: STM Tour Frequency Model Structure



The structure shown in Figure 19 consists of two linked models for each journey purpose. The first 'stop/go' model predicts whether the individual will make any tours, and so participate in activities in that purpose on that day. The second 'stop/go' model predicts if multiple tours are made. The same utility is used at each branch for the stop/go model, i.e. the probability of 'stopping' is the same at each decision point in the tree once at least one tour has been made.

The terms in the 0/1+ tour frequency models are outlined in Table 22.

Table 22: STM 0/1 + Tour Frequency Model Terms

Variables	Tour Purpose							
	Home-Work	Home-Bus.	Home-Prim.	Home-Sec.	Home-Ter.	Home-Shop	Home-Other	Work-Bus.
Age	√√	√		√		√√√√	√	
Gender	√	√						
Personal Income	√√√√	√			√	√√	√	√
Household Income			√	√√			√√	
Education Status	√√	√	√		√√√√	√	√	
Full Time Worker	√				√	√	√	√
Part Time Worker	√					√		
Other Worker Type	√√				√			
Looking After Home						√		
Pensioner Unemployed		√					√ √	
Job Type	√	√√√						√√√
Licence Holding	√					√	√	
Total Car Ownership		√√	√	√√		√	√	
Comp Car Ownership	√	√				√		√
Car Competition	√	√				√		
Household Size				√			√	
Numbers of Children							√√	
Accessibility	√	√			√	√	√	

Multiple ticks indicate multiple terms: the number of ticks equal to the number of terms.

Note that in the primary and secondary models there are far fewer terms. This reflects the greater homogeneity of the data: most children make one education tour per weekday during term-time.

Some of the models contain an accessibility effect, which account for higher tour frequency rates from more accessible origin zones.

The terms in the stop/go models are outlined in Table 23.

Table 23: STM Stop/go Model Terms

Variables	Tour Purpose							
	Home-Work	Home-Bus.	Home-Prim.	Home-Sec.	Home-Ter.	Home-Shop	Home-Other	Work-Bus.[8]
Age		√						
Household Income Education Status							√ √	
Full Time Worker							√	
Job Type	√							
Comp Car Ownership	√	√						
Car Competition	√							
Numbers of Children							√√	
Accessibility	√		√	√	√	√		

There are fewer terms in the multiple tour model because there is much less data than in the 0/1 + model.

For the business *detour* model, a total of four frequency models have been estimated, with separate models for outward and return detours, and for detours made as part of home-work and home-business tours. The models are simple binary models, with the alternatives ‘no detour’ and ‘detour’.

The detour models replicate higher rates of detour making on the return leg of home-based tours compared to outward legs. The models also replicate much higher rates of detour making where the primary destination is business than when the primary destination is work.

8.3.5 Home-Based Mode-Destination Models

Separate mode-destination models were estimated for each tour purpose. The models are estimated from two data-sets: HIS data and HTS data. The HIS data is older, and scaling terms are estimated to account for higher levels of error in the HIS data relative to the HTS data.

---

8 This model contains a constant only.

The attraction variables in the destination zone used varied by model purpose, and are summarised in Table 24.

Table 24: STM Mode-Destination Model Attraction Variables

Purpose	Attraction Variable
Work	Total employment
Business	Total employment
Primary Education	HIS: total education employment HTS: primary enrolments
Secondary Education	HIS: total education employment HTS: secondary enrolments
Tertiary Education	HIS: total education employment HTS: tertiary employment
Shopping	Retail employment
Other	Service employment Retail employment Population

The other model contains multiple attraction variables, reflecting the heterogeneous nature of the different journeys modelled in the other travel purpose.

The level of service variables used were generally the same between all tour purposes, although there the exact specification varied between models. The terms are outlined in Table 25, which contains a complete list of all terms used.

Table 25: STM Mode-Destination Model LOS Terms

	Car-Driver	Car-Passenger	Train	Bus	Bike	Walk	Taxi
Driving Cost	Cost						
Refundable Tolls	Cost						
Non-Refundable Tolls	Cost						Cost
Parking Cost	Cost						
Taxi Fare							Cost
Train Fare			Cost				
Ferry Fare			Cost				
Bus Fare			Cost	Cost			
Free-flow Car Time	Car Time	Car Time					
Congested Car Time	Car Time	Car Time					
Taxi Time							Taxi Time
Rail Time			Rail Time				
LRail Time			Rail Time				
Ferry Time			Rail Time				
Bus Time			Bus Time	Bus Time			
Access/Egress Time			AcEgTime	AcEgTime			
Initial Wait Time			Wait Time	Wait Time			
Other Wait Time			Wait Time	Wait Time			
Boardings			Boardings	Boardings			
Distance		CarP Dist			Bike Dist	Walk Dist	Taxi Dist

Socio-economic terms were estimated in the models, reflecting inter-personal and inter-household variation. The terms estimated varied between the different model purposes. To define the terms in implementation, segmentations have been defined. The number of segments used by purpose is given in Table 26.

Table 26: STM Mode-Destination Model Segmentations

Purpose	Segmentations	Total Segments
Home-Work	Car availability (8) Employment type (4) Personal income (4)	128
Home-Business	Car availability (8) Personal income (3)	24
Home-Primary	Car availability (5) Age (2)	10
Home-Secondary	Car availability (5) Household income (2)	10
Home-Tertiary	Car availability (6) Student status (2)	12
Home-Shopping	Car availability (6) Age / fare status (6)	36
Home-Other	Car availability (5) Personal income (2) Age / fare status (6)	60

8.3.6 Non-Home-Based Mode-Destination Models

In application, the non-home-based models are run after the home-based models have run. The non-home-based models predict the number of work-based tours and NHB business detours *dependent* on the numbers of home-work and home-business tours.

The models contain similar LOS terms to the home-based models. The attraction variable is total employment in the destination zone in both cases.

The work-based model is dependent on the output of the home-work model. A work based tour is illustrated in Figure 20.

The non-home-based model is dependent on the output of the home-work and home-business models and is illustrated in Figure 21. A single mode-destination model has been estimated for both outward and return detours.

Figure 20: STM Work-Based Tour

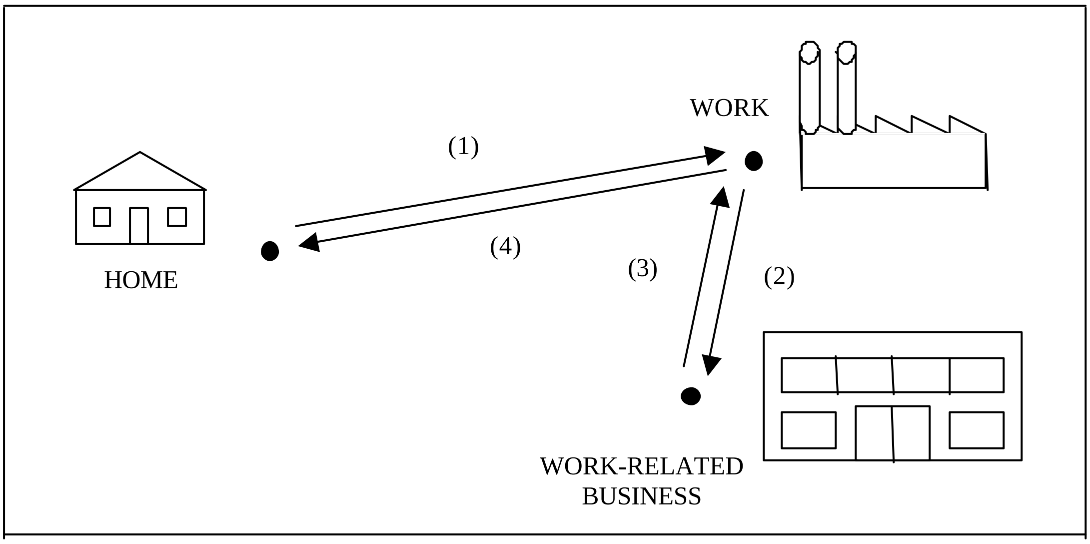
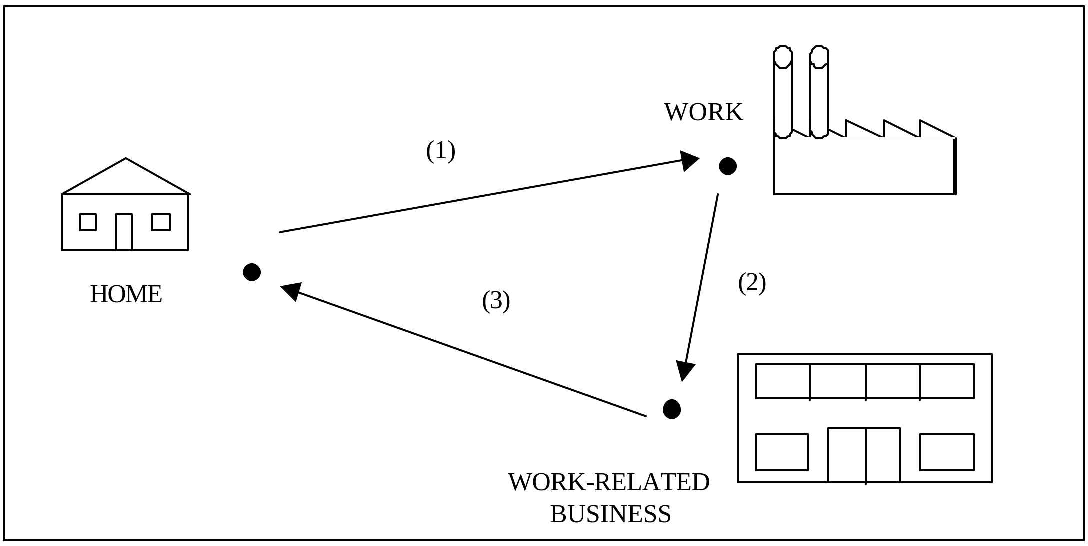


Figure 21: STM Non-Home-Based Business Detour



8.3.7 Assignment

Assignment for the STM is performed by the EMME/2 system, which is integrated with the travel demand models which are implemented in the matrix processor of that system.

9. CONCLUSIONS

This report has presented six different model systems which have been applied across a range of geographical levels of detail relevant to the UK context. The model systems share a common modular architecture, with individual sub-models to predict car-ownership, licence holding, travel frequency and mode and destination choice. Further, the modelling approach is common: all the models use disaggregate procedures to develop the sub-models, using logit and nested logit models, with linkages between the models to reflect the interdependence of the choices considered. The functions describing the utility of the alternatives also show considerable similarities.

The advantages offered by these similarities are that insights, model structures and even computer code developed for one area can be applied in another area. Detailed model coefficients are less readily transferable but even here the knowledge of values in one area can help in assessing the success of a model in another area. Only when data is very limited is it generally advisable to transfer coefficient values across areas.

However, while the models share a common structure and underlying behavioural rationale, the details of the model systems vary considerably. This variation is deliberate, as each model system has been tailored to reflect the client's individual policy needs and the availability of data in the area under study. That is, the model structure is specifically designed to allow consideration of the policy issues of local interest and to exploit the local data available. There is thus a considerable flexibility in the model designs.Further flexibility comes from the fact that these models can be adapted during their lifetime to deal with new policy issues or to take account of new data becoming available. These adaptations take the form of model extensions or updates.

Thus the combination of consistency of approach and local adaptation offers a number of advantages.

CREDITS

The authors of this report are James Fox, Andrew Daly and Hugh Gunn.

The models described in this report were developed by the following RAND Europe staff. The symbol * indicates the principal project leader(s).

'LMS': the Netherlands National Model

* Hugh Gunn
* Andrew Daly

Norwegian National Model

* Hugh Gunn
Mark Bradley
Gerard de Jong
Andrew Daly

'Antonin', the model of the conurbation of Paris

* Hugh Gunn
Mark Bradley
Jan Gerrit Tuinenga

'OTM', the model of the Copenhagen area

* Andrew Daly
Charlene Rohr

'SIMS', the Stockholm model

* Andrew Daly

'STM', the Strategic Transport Model of Sydney.

* Andrew Daly
* Charlene Rohr
James Fox
Hugh Gunn

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