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PETRA

The Forecast Model

Synthesis Report

September 1998

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PETRA

The Forecast Model

Synthesis Report

September 1998

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Table of Contents

1	**Introduction and Summary**	3
1.1	Introduction	3
1.2	Previous Reports	4
1.3	Summary	5
2	**The Model System**	9
2.1	PETRA Models	9
2.2	TDM	10
2.3	FLEET	16
2.4	EMIS	16
3	**Scenarios**	17
3.1	Model Populations	17
3.2	Scenarios Definition	19
4	**Scenario Results**	21
4.1	Car Availability	21
4.2	Tours and Purposes	25
4.3	Mode and destination choice	30
4.4	Emissions Calculation	36
5	**Discussion and Conclusion**	41
5.1	Future Developments of PETRA	42
6	**Appendix**	47
6.1	Licence Assignment	47
6.2	References	48
6.3	List of Abbreviations	49

1 Introduction and Summary

1.1 Introduction

The extent of the contribution of the transport sector to both local and global environmental pollution has been an increasing concern over the last decade. The political desire to address these problems has led to intensive discussions as to the range and efficacy of available policy instruments. One of the earliest discussions reflected the policy dichotomy between ' command and control' regulation or 'economic instruments', with the latter gaining broad acceptance among policy makers, particularly as a means to reduce the environmental impact of transport.

However, the significance of the potential impact of many of these instruments on travel demand, mode choice and the technological improvement of transport concepts underline the need for greater a priori understanding of their latent role. PETRA, a Danish acronym for Passenger Transport, is a research project that endeavours to meet the challenge, through the construction of a passenger transport model for policy analysis on the national level.

The primary objective underlying the development of the PETRA model system, is to assess the impact of discrete policy measures on private passenger travel demand in Denmark. A secondary objective is that the developed model should contribute to extending the basis of planning capability in national transport policy making.

The PETRA model system consists of a series of econometric models, at a disaggregate behavioural level, with the aim of forecasting national travel demand. Hence, the model system captures a wide range of individual and household decisions, about car ownership, car utilisation, mode and destination choice, frequency of travel, etc, and provides a detailed representation of the passenger travel market.

The travel demand models are based on simulations of the transport behaviour of individuals. Thus, the model system retains a high degree of disaggregation. The estimated relations are used to forecast the consequences at the aggregate level from policy implementations as well as from socio-economic and demographic changes in the population.

The PETRA model system is designed to consider different scenarios, defined in terms of those factors that are believed to influence the demand for travel. The model is capable of embodying changes in such factors as relative prices, accessibility and the costs of using various modes of transport. This is in addition to changes in income, and any change in the scale and composition of the population, that might affect the demand for transport.

The outputs from the system are directly linked to those policy criteria that relate to the environment: energy use and emissions, demand for travel, tax revenue, the size of the car fleet, etc. The results can be produced at different levels of aggregation for different travel purposes, modes of travel and for specific groups of people according to age, sex, income, etc.

This report has been prepared by a team composed of staff from COWI, and headed by Claus Hvashøj Jørgensen. The other members are Mogens Fosgerau, Jørgen Jordal-Jørgensen, Niels Buus Kristensen and Lars Grue Jensen. This report has been prepared by Mogens Fosgerau and Jørgen Jordal-Jørgensen.

A number of external contributions have been made to the project; DMU, represented by Linda Christensen and Søren K. Jensen, has delivered data from the TU travel survey, in addition to car and bus network data. Eric Verroen and Tom van Maanen of TNO Policy Research provided assistance in the early stages of the project, with comments on the initial concepts for model design.

The Team was assisted throughout by a Steering Committee, and a Support Group. The former was composed of the following: Susanne Krawack, (Danish Transport Council), Staffan Widlert, (SIKA, Sweden), Farideh Ramjerdi (TØI, Norway) and Erik Toft (Danish Ministry of Transport). The Support Group comprises Steen Leleur (TU, IVTB), Knud Erik Andersen (The Road Directorate), Thomas Bjørner (AKF), Anders Nørskov (Ministry of Finance), Uffe Jacobsen (TTR, Copenhagen Business School), Jørgen Horstman (Danish Environmental Protection Agency), Erik Grip and Søren Dalbro (Central Bureau of Statistics), Maj Dang-Trong (Danish Energy Agency), Erik Bagge (DSB) and Stig P. Christensen (COWI).

We have also received valuable and constructive comments from both the Steering Committee and the Support Group as well as from the Institute of Transport Economics (TØI) in Norway. However, the Study Team is solely responsible for any errors or misunderstandings in the model or in this report.

The PETRA study was initiated in March 1994 and is funded by research grants from the Danish Transport Council, the Danish Energy Research Programme and the Danish Ministry of Transport.

1.2 Previous Reports

This report is part of a series of papers reporting on the work done on the PETRA project.

- Working Paper no. 1, Modelling Concept
- Working Paper no. 2, Preliminary Analysis of Transportation Surveys
- Working Paper no. 3, Weights
- Working Paper no. 4, The Licence Holding Model
- Working Paper no. 5, The Cohort Model
- Working Paper no. 6, Car Fleet Model
- Working Paper no. 7, The Travel Demand Module
- Working Paper no. 8, Data
- Working Paper no. 9, Technical Implementation

PETRA Working Paper no. 1 set out the modelling concept prior to the initiation of the estimation work. Working Paper no. 2 was a preliminary analysis of the TU surveys undertaken by DMU, providing initial documentation that sufficient variation was present in the TU data, to allow the estimation of a sophisticated model.

The next working papers relate directly to the forecast system that is used to generate the results presented in this report.

PETRA Working Paper no. 3 describes the calculation of weights that are used to generate the data set, representative for the Danish population, upon which the model is based. Working Papers 4 and 5 describe the formulation and estimation of the models that forecast future licence holding at the aggregate and individual levels.

PETRA also includes a model that endeavours to encapsulate developments in the domestic car fleet. The main part is an accounting model that projects the car fleet from year to year. However, this is supplemented by a sub-model that distributes those new cars entering the fleet across a number of 'typical' car types. A more detailed exposition of the precise methodology is provided in Working Paper no. 6. The core of PETRA, including most of the behavioural relations, is the Travel Demand Module, which is detailed in Working Paper no. 7.

1.3 Summary

Objective

The aim of the PETRA project was to develop a model that could recreate the main aspects involved in the demand for travel. The attainment of this objective requires that the model system should retain a high degree of detail and be based on disaggregate models. This was both to ensure an accurate representation of the underlying behavioural intentions, and allow analysis of the underlying travel demand and related aspects across a number of dimensions.

This has been achieved in all main respects. The model system is capable of close reproduction of the observed behaviour and generally responds as expected to changes, exhibiting consistent and plausible reactions. The dis-aggregation of the forecast population, according to the various criteria, allows the model to clearly illustrates the behavioural differences between different population segments. Thus, it seems reasonable to conclude that PETRA is capable of detailed analyses of the distributional and behavioural effects of policy changes.

Model concept and validity of results

The model introduces a new approach to the modelling of mode and distance choice, and chain choice. The approach involves the definition of a number of tour types, with mode and destination choice models estimated separately for each tour type. The mode and destination choice are quite good and so different that, statistically, the distinction between tour types in these models is strongly justified. All individuals can in principle choose any tour type, and a model is required to determine which tours are chosen by which individual. This is the chain choice model, which is an extension of the idea underlying the traditional frequency model, and inspired by developments in activity based modelling.

The construction of the chain choice model has been successful in that the model, assigning probabilities for individuals choosing various combinations of tours, fits the data well. The model does not, however, respond as strongly as we would expect to changes in accessibility[1]. There are some possibilities to reconstruct the model, to ensure that it can distinguish more clearly between different population segments, and, thus, react more strongly to changes in accessibility. The report suggests some potential improvements for the chain choice model, to be pursued in a new project.

PETRA also includes a model for household car availability, which appears to work in a satisfactory manner. The interactions between cohort, or penetration type effects, and income, are represented in a way that suggests that the income elasticity of earlier time series analyses may be too high, and that car ownership will continue to grow over the next 20 years, even if income were constant. This has the implication that it may be harder to control the size of the car fleet through taxation, than the time series elasticities suggest.

Like the chain choice model, the car availability model is less sensitive than expected to increased fuel prices and decreased accessibility. Predicted car availability does not decrease as much as expected when fuel prices are increased. It is believed that the problem is unlikely to be solved by reformulation of the model, as it probably results from using cross-sectional data with no variation in the fuel price. The utilisation of more cross-sectional TU data in future work on PETRA would be expected to remedy this.

The whole model system, including the car availability model, would benefit from the improved quality of the underlying network data which is currently considered to be weak in places.

The cohort effect is represented in two models for aggregate and individual licence holding. These models show very clearly how the cohort effect, the penetration of licence holding into all population segments, is still taking place. Much of the penetration process has been completed, but the licence holding rates for older women are still expected to increase with implications for car ownership.

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[1] Generalised travel costs

PETRA keeps track of the development of the car fleet in a satellite model. This is used to compute the average fuel consumption per kilometre for the average car. This figure is then combined with the forecast of travel demand to show the consequences for the amounts of various emissions. In future revisions of PETRA, a true emissions model could be constructed that would exploit the disaggregated data in the model with respect to trip lengths, cold starts and location of trips on the network.

Structure of report

The following chapter 2 presents an overview of the model system while chapter 3 constructs the forecast populations and defines scenarios for which results are presented in chapter 4. Discussion and conclusions are given in chapter 5 which also points out directions for future work on PETRA. References and abbreviations are given in chapter 6.

2 The Model System

2.1 PETRA Models

The PETRA system consists of a number of models, presented in this chapter.

TDM

The heart of PETRA is the Travel Demand Module, TDM, which again consists of a number of sub-models. At the most general level TDM predicts car availability for each household in the model population. A person is selected in each household, the IP. For each IP, the TDM predicts probabilities for choosing different combinations of travel purposes and travel patterns. These predictions are conditional on car availability.

The possible combinations of travel patterns and purposes, range from the simplest option which is to stay at home, to more complicated patterns consisting of two tours and with two purposes on the first tour.

At the most basic level, the TDM predicts mode and destination choice for each of the tours in the travel pattern. These choices are again conditional on car availability and choice of travel pattern and purposes.

COHORT and LICENCE

A premiss for PETRA is the existence of cohort or diffusion effects of car ownership. These effects result in increased car ownership as the generations change, independently of income growth. The effects are modelled through two satellite models; COHORT models the licence holding rates for groups defined by age and sex and projects these rates from the base year to the forecast year, and LICENCE is used to distribute licences on individuals such that the licence holding rates for the model population in the forecast year match those predicted by COHORT.

Thus, COHORT and LICENCE generate licence holding data which are taken as exogenous by the TDM. The TDM predicts travel demand and the demand for cars. The total number of cars is output to the FLEET module, which keeps account of the cars in the Danish car fleet.

FLEET

The FLEET module holds the current Danish car fleet with cars divided into groups defined by car type and vintage. The FLEET module projects the car fleet year by year, given the size of the car fleet for the forecast year output by the TDM. A number of cars are scrapped each year, according to fixed scrapping

rates, and accordingly leave the fleet. The number of new cars entering is determined such that the size of fleet predicted by the TDM is matched. The distribution of entering cars on car types is determined by the Car Choice Model, CCM, which is a submodel of FLEET.

CCM

The CCM is developed under a project prior to PETRA and takes car prices, including taxes, fuel prices and income as inputs. The composition of new car sales is the output.

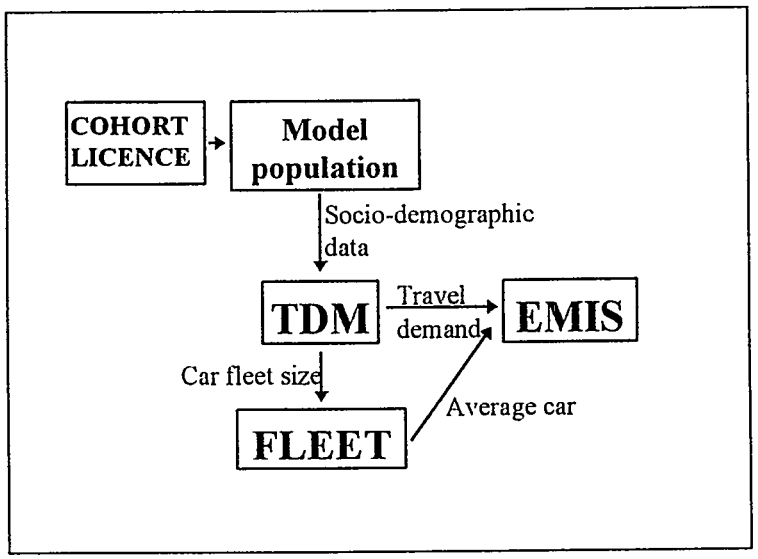
EMIS

Fuel consumption and emission rates are calculated for the average car in FLEET. Together with the predicted travel demand output from the TDM they are used to calculate total emission for the car kilometres travelled.

The system

The interactions of the PETRA components are illustrated in the following figure.

Figure 2-1. PETRA overview



2.2 TDM

2.2.1 TDM Conventions

Household persons

The TDM database contains information concerning several people in the households. Three persons are always identified in each household, they may not all be different persons. One person has been interviewed in the TU survey, for this person the TU travel diary is recorded and it is him that the choices of travel chain, mode and destination in the TDM concern. This person is referred to as the IP, the interview person.

The other central person in the household is the head of household, the HP. The HP is defined as the person in the household with the highest income. The HP is taken to be central for the determination of car availability. It is his expected car kilometrage that enters the car availability model.

The third person is the partner, when one exists in the household. The partner is defined as the partner of the HP or the IP according to who is the main person in the relevant part of the TDM. Socio-economic characteristics for the partner enter the various models in the TDM.

Household types

The TDM operates with three types of households. First, households are divided into single and two adult households: Singles and couples. Secondly, a distinction is made between "normal" single adult households and auxiliary single adult households consisting of, e.g., adult children living with their parents. This last distinction is used at some points in the TDM.

Trips, tours and chains

The TDM distinguishes between travel on three levels. The basic travel unit is the trip, which is defined as the travel between two locations where some travel purpose is engaged in. The travel from home to work is a trip, while the travel from home to a bus interchange on the way to work is not a (complete) trip. A tour is a sequence of trips starting and ending at home. Finally, a chain is the sequence of tours undertaken in a day.

Modes

The TDM operates with the following modes. The modes are defined as an aggregation of the more detailed definition of modes used in the TU.

Table 2-1. Definition of modes

Model mode	TU modes
Walk	Walk
Bicycle	Bicycle, moped
Car	MC, car, taxi, truck driver
Car passenger	Car passenger
Bus	Bus, S-train
Train	Train

In the following summary tables, the walk and bicycle modes are aggregated to a slow mode even though they are modelled as separate modes.

Travel purposes

Four types of destinations are used in the model; the first is home, the other three are destinations where some activity is engaged in which is the purpose of travel. For convenience, they are coded using the following numbering. A detailed definition is given in [1].

1. Home — The residence of the IP
2. Work — Work, business, education
3. Errand — Errands of all kinds, including shopping, collecting and bringing children
4. Leisure — Visiting family or friends, amusement, weekend cottage, excursion, sport, meeting and walk

Tour types

Mode and destination choice is modelled separately, with a sub-model for each of eleven tour types. Below, the tour types are given together with the naming

convention adopted for the submodels. Tours are either main or minor and can be either simple or triangular. The main tour is considered as the most important and it always includes the work purpose if present in the destinations chosen. The minor tour is the other tour when two tours are chosen. A simple tour goes from the residence to one single destination and back, where a triangular tour has two destinations away from home.

Tours are divided into three groups: Simple main tours, triangular main tours and simple minor tours. There are few triangular minor tours in the data and the corresponding alternatives do not exist in the model. The first group is simple main tours. That is, tours with the following purposes.

Name	Sequence
12	Home - work - home
12x	Home - work - home, followed by a minor tour
13	Home - errand - home
14	Home - leisure - home

The second group consists of triangular main tours.

Name	Sequence
123	Home - work - errand - home
123x	Home - work - errand - home, followed by a minor tour
124x	Home - work - leisure - home, followed by a minor tour
134	Home - errand - leisure - home

Finally, the third group consists of simple minor tours.

Name	Sequence
214	Home - leisure - home, following a work tour
314	Home - leisure - home, following an errand tour
x13	Home - errand - home, following any main tour

Chains

The tours are assembled into chains. The TDM operates with 13 different possible chains, which cover most of the chains actually chosen, although a virtually infinite number of different chains are possible in principle.

Table 2-2. Chain choice alternatives

Chain	Main tour type	Minor tour type
12	12	-
123	123	-
1213	12x	x13
12313	123x	x13
124	124x	-
1214	12x	214
12414	124x	314
12314	123x	314
12413	124x	x13
13	13	-
14	14	-
134	134	-
Home	-	-

Urbanisation variable

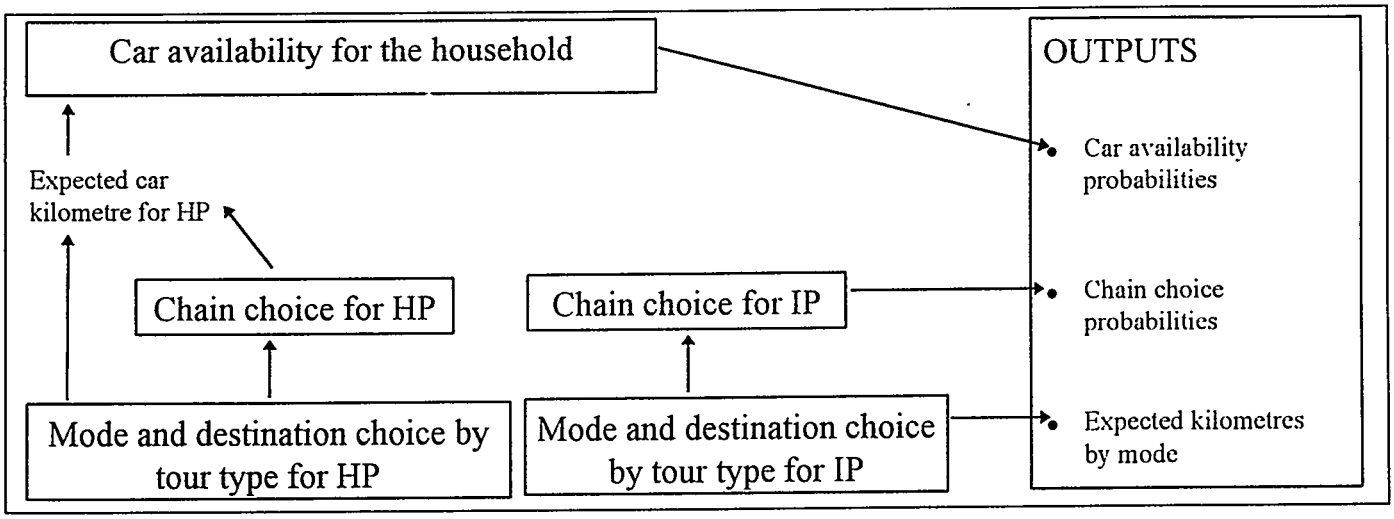
The TDM database contains an urbanisation variable, which is a typology of cities according to size with an extra category for rural areas. The variable is used in the models and is also used in this report for segmentation of forecasts.

URBAN	Definition
11	Copenhagen, except
12	Frederiksberg
20	Other Cph suburbs
30	>100,000 inhabitants
41	>70,000 inhabitants
42-43	22-60,000 inhabitants
44	10-22,000 inhabitants
50	2-10,000 inhabitants
60	200-2000 inhabitants
70	Rural areas

2.2.2 TDM interactions

The interactions between the TDM models are illustrated in the following figure.

Figure 2-2. TDM interactions



A TDM run consists of a series of steps.

1. The mode and destination choice sub-models are applied for all HPs in the database. Logsums from the sub-models are passed on to the chain choice model which generates a probability distribution over the possible chains. These probabilities are used with the expected car kilometres from each of the sub-models, to yield expected car kilometres for the HP.

   This computation is performed three times, conditional on car availability status. The runs assume that the household has 0, 1 and 2 cars available.

2. The conditional expected car kilometres for the HP together with data for the HP and the partner of the HP enter the car availability model to give the forecast car availability status for each sample household. The computed household probabilities of having 0, 1 and 2+ cars available are retained for further use.

3. In the third step, the mode and destination choice submodels are applied for each IP. They are applied three times, once for each of the three possible car availability statuses of the household.

   Expected kilometres by mode conditional on car availability are calculated for each IP and retained for further use. Also logsums for each submodel are calculated conditional on car availability. The logsums are output to the chain choice model.

   The chain choice model calculates probabilities for the various possible chain choices, for each IP and conditional on household car availability. The probabilities are retained for further use.

Thus, a TDM run results in a table containing information on the expected travel demand of the IP. The table has the following contents.

- ID, allowing the information in the table to be combined with all the individual and household information in the PETRA database.
- Probabilities for the three possible car availability statuses.
- Expected kilometres by mode, conditional on car availability.
- Chain choice probabilities, conditional on car availability.

The table is further linked to tables containing weights that reweigh the sample to be representative of both the 1995 population, and the forecast 2020 population. Weights are available to make the sample representative at both the individual level and household level.

2.2.3 Policy variables

The main policy variables relate to the supply and cost of transport services. Cost and time consumption are relevant for all modes, and the cost of the car modes is the fuel price, which is a central variable for analysis. Only one common fuel price is used in the TDM, the CCM distinguishes between petrol and diesel. Level of service variables also enter the models, however, with only limited impact on the forecasts. Income and the cost of car ownership are in the car availability model.

2.2.4 Analysis dimensions

All the information in the PETRA database can be used to segment the model population and thus generate separate results for any segment. A number of socio-demographic variables enter the models, such that the model behaviour is different for groups that differ on these variables. We list the main variables below.

- Sex
- Marital status, household type
- Number and age of children
- Occupation type
- Education level
- Income
- Age
- Region, at different levels of aggregation from 1500 zones to national level
- Urbanisation
- Day

2.3 FLEET

The FLEET is not implemented in the present version of PETRA. The plan is to keep the initial car fleet for 1995, with the number of cars distributed on a matrix of 25 car types by 11 vintages. The production of a forecast car fleet for a future year, requires the future number of cars in the fleet to be received from the TDM. The number of cars in intervening years is calculated by linear interpolation. FLEET calculates a type and vintage matrix for any year based on the preceding year; First, fixed scrap rates by type and vintage are applied and the remaining cars are made one year older. The difference between the remaining number of cars and the interpolated target is made up of new cars entering the fleet. The distribution of new cars on types is determined by the CCM, the car choice model.

The CCM is estimated on a cross-country data set of car sales for seven countries. The variables that determine the distribution on types are average GDP per capita, diesel and petrol prices, fuel consumption by car type and car prices and annual taxes by type. These variables as well as the scrap rates can be changed for scenario analysis.

The output of FLEET is the vehicle fleet size for given years by vintage and car type, along with fuel consumption for each car type. This information is combined to give average fuel consumption per kilometre for the fleet.

2.4 EMIS

The EMIS module is still relatively rudimentary and there is plenty of scope for improvement with more detail and more realistic assumptions concerning future technical developments in the car fleet.

As it stands, the module utilises fixed emission rates per kilometre found in [20] for the year 2010. These rates are applied to the total kilometres by car and public transport predicted by the TDM.

3 Scenarios

3.1 Model Populations

3.1.1 Construction

Model years

The model is run for two years, with a base year of 1995, which is the year when the TU data were collected. Year 2020 is selected as the future year. In 2020, the licence holding penetration process is almost complete.

Weights

The 1995 TU data base consists of a sample of almost 15,000 individuals in as many households. Weights have been calculated at both individual and household level to make the sample meet a number of targets for the actual Danish population in 1995 and 2020. Targets are, inter alia, population by age group and employment. The calculation of weights is described in [6].

Income

The income measure employed in all models is net income after taxes. Income is assumed to grow by 2% each of the years until 2020, to a compounded total of 64%. The income growth is implemented as a constant relative change of all individual incomes.

Three model populations

Three model populations are constructed; the first is the base 1995 population, which is also used for estimation. In the second, the year is changed to 2020 which has consequences for the licence holding rates. The third model population is also for 2020 with incomes increased by 64% relative to the 1995 situation. The objective of the three populations is to analyse the effects of time and income growth separately. The model populations are named as follows.

- 1995 Base
- 2020 Base
- 2020 IG (income growth)

Licences

The year and the income level partly determine the licence holding status for the individuals in the model population.

The actual licence holding status is used for the 1995 Base population, and the licence holding rates are increased relative to the 1995 Base population for both the 2020 Base and the 2020 IG populations. Therefore, a number of licences are assigned to individuals in the two 2020 populations in the following way; First,

COHORT is applied to give average licence holding rates for 2020. These rates are higher than the 1995 rates. The forecast rates enter the LICENCE model to give probabilities at individual level. The LICENCE probabilities are used to assign licences in 2020 to individuals with no licence in 1995.

Income

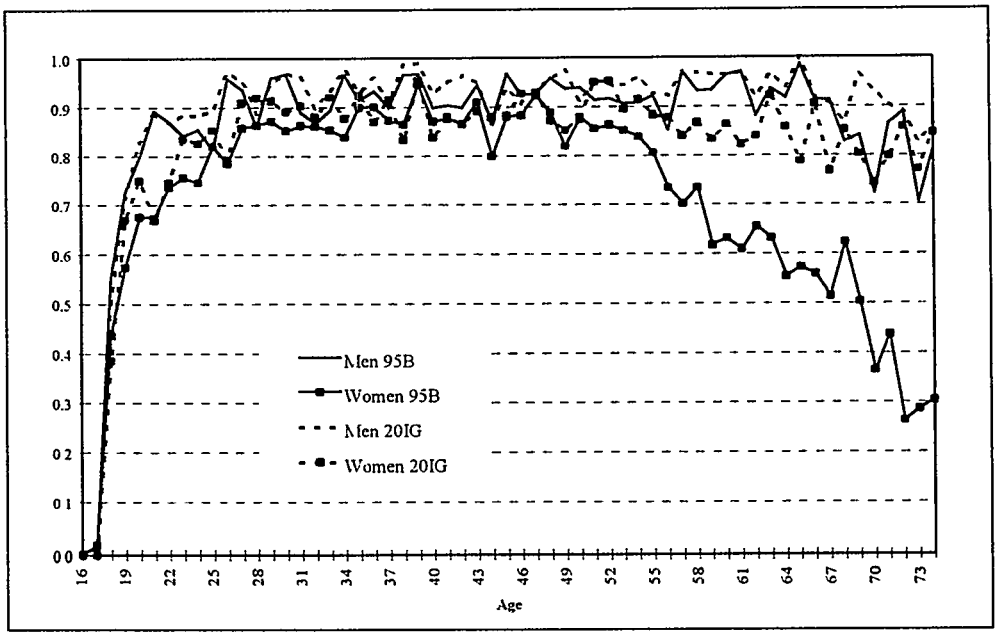
If the assumed income growth of 64% was used in the weighting, this would result in low income individuals counting for little, and high income individuals would represent the main part of the population. We assume that the present relative income distribution is preserved within the forecast population.

Therefore, the 1995 income and the 1995 targets for income are used to calculate the weights for the 2020 population. Incomes are subsequently increased by 64% for all individuals with no consequences for the weights.

3.1.2 Results

The main difference between the three model populations is the licence holding rates. That apart, the only change is the weights assigned to different population segments. The projected licence holding rates are shown below for the 1995 Base and 2020 IG scenarios. There are only minor differences between the 2020 Base and the 2020 IG scenarios.

Figure 3-1. Licence holding rates



A few points can be noted: First, licence holding increases from 1995 to 2020 both for men and women. Second, fewer women than men obtain a driver's licence, and, when they do, they do so later in life. Third, in the 1995 scenario, the share of women over 50 with a licence is much lower than for men and the difference increases with age. In the 2020 scenario, this difference has almost disappeared due to the cohort effect.

3.2 Scenarios Definition

A number of scenarios are selected to generate forecasts, within each of the three model populations. These scenarios are illustrated in the following table. For each model population, a forecast is made with the current fuel price and generally with all variables left unchanged. This yields three forecasts showing

- the 1995 base situation,
- population structural change: the cohort effect along with population growth and relative ageing,
- and the effect of income change together with population structural change.

The fuel price is increased in two scenarios; first with the 1995 Base population to show the reaction today to a fuel price increase, and secondly with the 2020 IG population, to show the effect of a fuel price increase for the future population after income growth has taken place. The 1995 fuel price is 5.92 DKK/litre, after the increase the fuel price in the scenarios is assumed to be 12.00 DKK/litre.

The table below provides the code adopted for the scenarios.

Table 3-3. Naming of the five scenarios

Population	Current fuel price	Fuel price up
1995 Base	95B	95B+
2020 Base	20B	
2020 IG	20IG	20IG+

4 Scenario Results

4.1 Car Availability

The car availability model produces probabilities for different car availability statuses for single and two adult households. In the model, singles can have 0 or 1+ cars and couples can have 0, 1 or 2+ cars. Using averages from the TU, 1+ cars is taken to be 1.071 cars and 2+ cars is taken to be 2.092 cars. These rates set an upper limit on the number of cars that the model can predict.

The model takes the expected car kilometres calculated conditional on the household car availability as input. Expected car kilometres are calculated for the HP using the mode and destination choice submodels together with the chain choice model.

4.1.1 Results

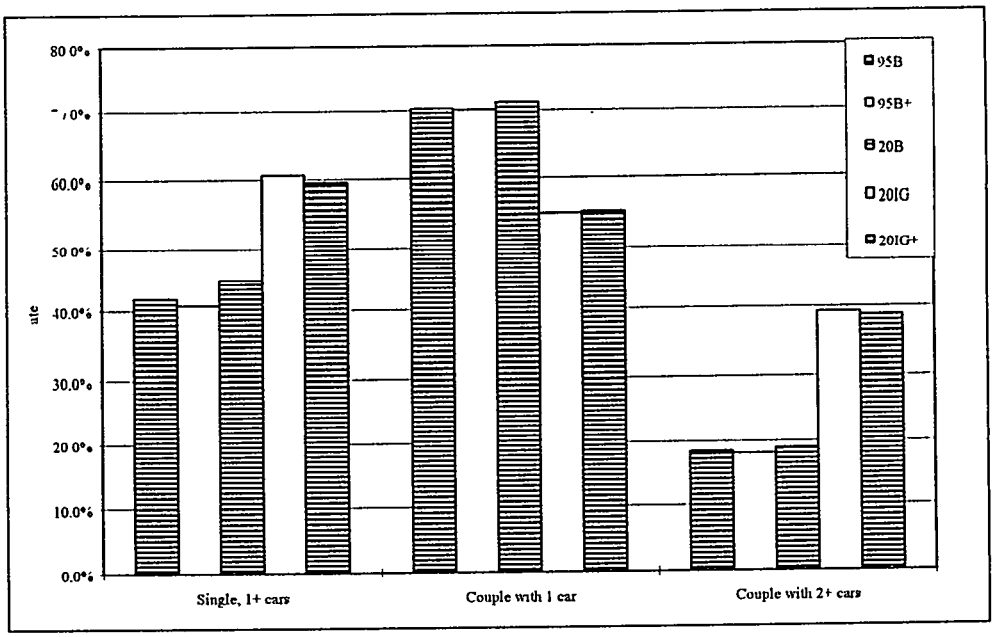
Running the TDM with the five scenarios, yields the following general results on car availability. From the table it is seen that in the 95B scenario 41.9% of single adult households have a car available and that 18.4% of two adult households have at least two cars available.

Table 4-1.Car availability by household type, percent of households

	95B	95B+	20B	20IG	20IG+
Single, 1+ cars	41.9%	40.7%	44.7%	60.6%	59.6%
Couple with 1 car	70.3%	70.1%	71.2%	55.4%	55.7%
Couple with 2+ cars	18.4%	18.0%	18.9%	39.2%	38.7%
Total no. of cars '000	1,587	1,563	1,745	2,226	2,205
Change relative to 95B		-1.5%	10.0%	40.3%	39.0%

The same figures are shown on the following graph.

Figure 4-1. Car availability by household type



TDM vs. actual car fleet

The size of the Danish passenger car fleet was 1,673,000 cars, at the end of 1995. This figure includes about 100,000 cars registered with a company rather than an individual. When an individual has the daily use of one of these latter cars for private purposes, then, according to Danish Law, it needs to be registered with the authorities. It is uncertain whether this requirement is always met. However, less than 1000 cars were registered with a company as the owner, and an individual as the user. Approximately 15,000 cars are used as taxis, ambulances, hire cars, in driving schools, etc.

PETRA underestimates the number of cars by 86,000 or 5%. The number of cars given in the TU is the number of cars available to the households, not the number of cars owned. The discrepancy could thus be explained by company owned cars not being counted in the TU survey.

The TU survey asks for the availability of passenger cars. In Denmark, approximately 65,000 small vans are used as passenger cars for private transportation. The wording of the TU questionnaire suggests that many of these vans are unlikely to be counted as passenger cars in the TU; still, some of them may be counted thus contributing to the discrepancy between the TU and number of cars registered.

Comparing scenarios

A comparison of the B and B+ scenarios shows that the predicted response to a fuel price increase is limited. Otherwise the response is as expected with single adult households reacting most.

Total car availability increases 10% from 95B to 20B. Most of the increase is due to a larger forecast population. The increase in the car availability *rates* follow mainly from increased licence holding rates but also from changed relative weights of different population segments in the population. The increase is largest for single adult households.

Total car availability increases a further 30% from 20B to 20IG as a result of the income increase. In two adult households, the number of cars per household increases from 1.10 to 1.35 while in single adult households the rate increases from 0.45 to 0.61.

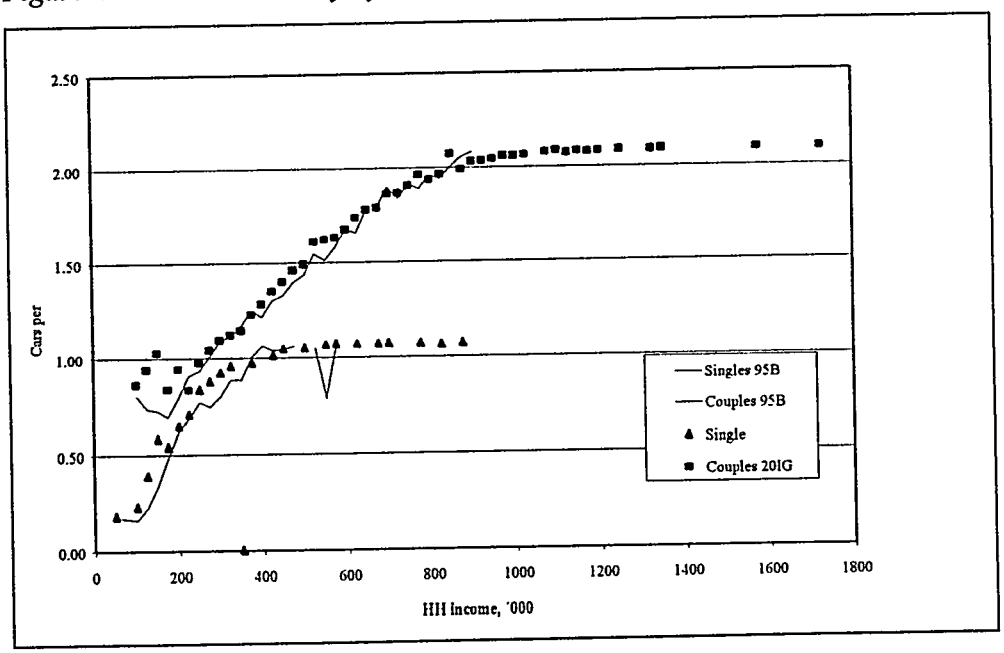
Elasticities

A comparison of 20B with 20IG indicates an increase in the predicted car fleet of 28% on an income increase of 64% corresponding to an income elasticity of 0.43.

Income

The following figure shows predicted car availability by income for the 95B and 20IG scenarios, for both singles and couples. Car availability is expected to increase with income towards the saturation levels for single and couple households. Generally, the rates increase at each income level due to increased licence holding. At the same time the increase in income implies a rightward shift of the curves.

Figure 4-2. Car availability by income, 95B and 20IG



Urbanisation

The following two graphs show the predicted car availability by urbanisation for single and couple households. A translation of the urbanisation codes is given on page 11.

Car availability is lowest in central Copenhagen (code 11) and higher in the affluent Copenhagen suburbs (codes 12 and 20). For the large cities (code 30), it is about the same level as in Copenhagen and then increases with decreasing urbanisation. There is most variation in the rates for singles.

Compared with 95B, the fuel price increase in 95B+ has similar small effect at all urbanisation levels and the effect is largest for singles. The different composi-

tion of the population, and the increased licence holding, increases car availability in 20B. The increase is most for singles, where the increase tends to be larger at low urbanisation levels. Increased income in 20IG increases car availability markedly at all levels of urbanisation. The effect of increasing the fuel price in 20IG+ is most significant for singles at mid urbanisation levels but again not very large.

Figure 4-3. Car availability by urbanisation, couples

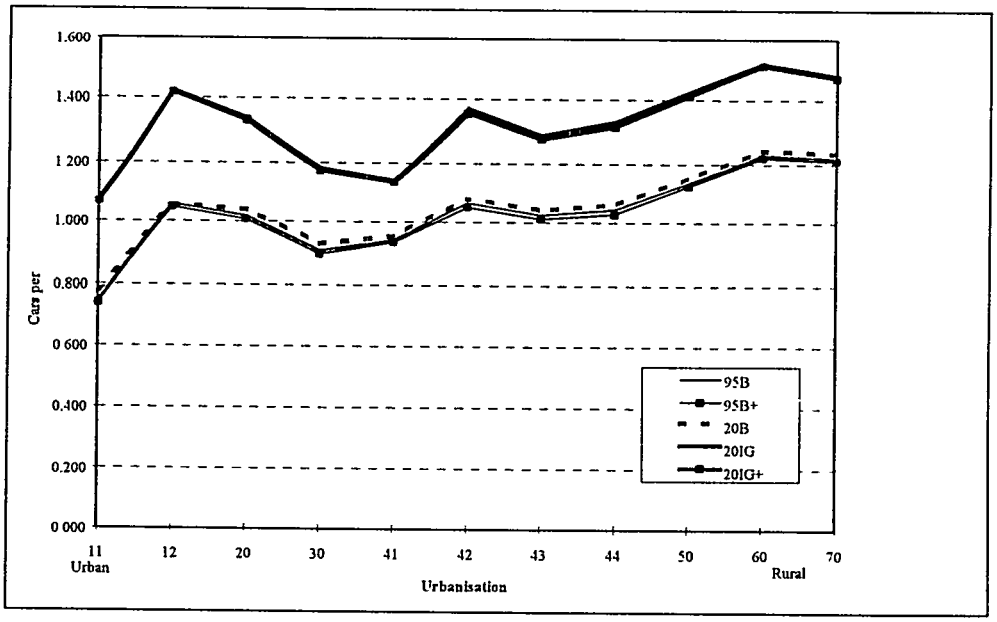
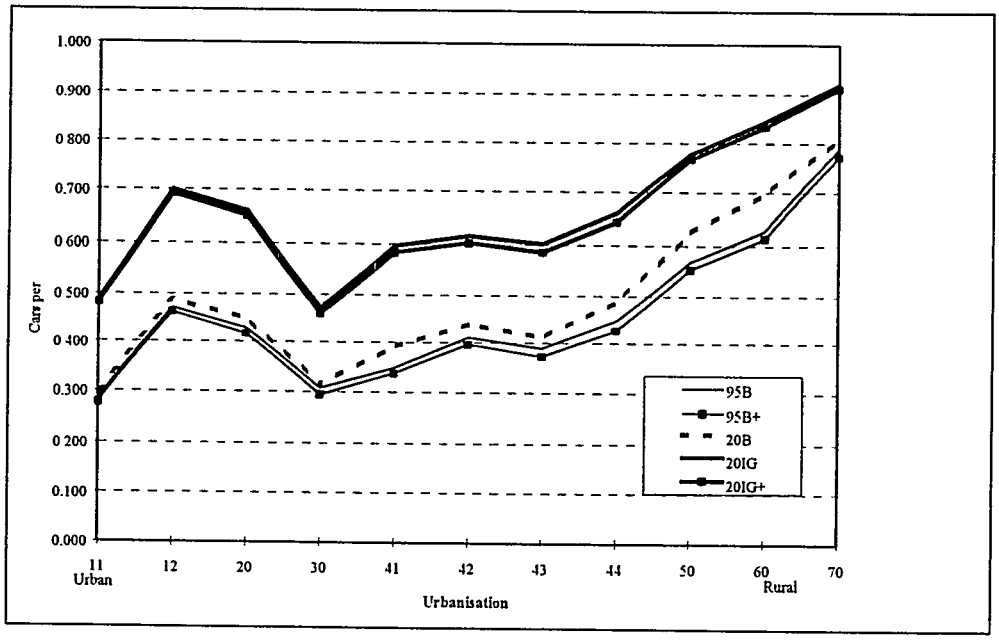


Figure 4-4. Car availability by urbanisation, singles



4.1.2 Discussion

Income elasticity

From 1985 to 1995, Danish GDP has grown on average 1.7% per year while car ownership has grown by 1.1% per year, corresponding to an income elasticity of car ownership of 0.65. In [11] it is concluded that the long term income elasticity of car ownership probably is around 0.8-0.9, based on some time series analyses of car ownership in Denmark. The income elasticity found in the present analysis of cross-section data of 0.4 is thus lower than these elasticities.

In [17] we assert that the income elasticity, estimated on time series data, is in fact overestimated, being a combination of income and cohort effects and population growth. Here we find that income growth, population structural change and the cohort effect up to the year 2020, would result in a 40% increase in car ownership, or an "elasticity" of 0.6. This is still lower than the elasticity found in time series analyses, although perhaps this could be explained by the higher cohort effect in the past. The cohort effect is almost exhausted by the year 2020.

Price elasticity

Goodwin concludes in a review [15] that the fuel price elasticity of car ownership probably is up to -0.3. Oum et al. in another review find long run cost elasticities of automobile usage of -0.2 to -0.3 for United States and Australia. This implies cost elasticities of car ownership of perhaps half that since the response to a cost increase is partly reduced usage of each car and partly reduced car ownership.

The sensitivity of the current car availability model to fuel costs implies an elasticity of -0.02, which is rather low in contrast to the elasticities quoted above. Previous work undertaken by COWI, has assumed an elasticity for Denmark of between -0.12 and -0.30, with the current consensus being that the true elasticity is nearer -0.12. The car availability model uses expected car kilometres conditional on car availability, to estimate the influence of variable costs on car availability. This is very direct, so we feel the problem with low sensitivity to fuel price changes is not in formulation of the model. The implication is that it results from the nature of the cross-sectional data, which has no variation in the fuel price.

Thus, it is believed that the addition of more data would be beneficial in two ways: First, by providing some variation in fuel costs and secondly, the correlation between time and monetary costs will be reduced allowing an improved formulation of the mode and destination choice models.

4.2 Tours and Purposes

PETRA includes 11 different mode and destination choice models for as many different tour types, which are combined into 11 possible chain choices. Each individual chooses between the possible chains, with probabilities given by the chain choice model. The choice of a travel chain is, in effect, a choice of what travel purposes, if any, to undertake in a day and how to arrange the purposes into tours.

4.2.1 Results

Tours and trips

Table 4-2 summarises the predicted number of trips and tours in the five scenarios. An increase in the fuel price has only a marginal effect on the number of trips and tours. It hardly changes the ratio of trips to tours at all, meaning no substitution of triangular tours for two tours. A change in the population from 95B to 20B, decreases the number of trips and tours and also the ratio of trips to tours. An increase in income increases all three figures such that in 20IG, trip and tour rates are lower than in 95B while the number of trips per tour is almost the same.

Table 4-2. No of tours and trips per IP

No.	95B	95B+	20B	20IG	20IG+
Tours	0.986	0.982	0.960	0.965	0.961
Trips	2.118	2.109	2.059	2.074	2.064
Trips/tour	2.148	2.148	2.145	2.149	2.148

Travel purposes

Table 4-3 summarises the number of times each travel purpose is met. Thus, in 95B, 41.5% of all IPs have a tour involving the work purpose. Errand purposes are perhaps a bit more flexible, but otherwise the response to the increased fuel price is limited. Changing the population from 95B to 20B, decreases the number of times the work place is visited noticeably and increases the stay home rate, otherwise the changes are small. An increase in income leads to more work and errand tours and a smaller stay home rate.

The changes implied by the scenarios are all reasonable, or at least do not contradict expectations. However, the changes are rather small, as noted earlier.

Table 4-3.Likelihood of chains including different purposes

Chain	95B	95B+	20B	20IG	20IG+
Work	41.5%	41.3%	38.2%	38.5%	38.3%
Errand	33.1%	32.9%	33.3%	33.9%	33.6%
Leisure	36.6%	36.5%	36.7%	36.7%	36.6%
Stay home	19.3%	19.6%	20.5%	20.1%	20.4%

The following Table 4-4 shows the distribution on chains for the five scenarios.

Table 4-4. Chain choice distribution

Chain	95B	95B+	20B	20IG	20IG+
12	16.4%	16.5%	15.2%	15.1%	15.1%
1213	5.6%	5.5%	5.2%	5.3%	5.2%
1214	8.1%	8.1%	7.4%	7.4%	7.4%
123	4.7%	4.7%	4.4%	4.5%	4.4%
12313	1.4%	1.4%	1.3%	1.3%	1.3%
12314	2.0%	2.0%	1.8%	1.9%	1.9%
124	2.4%	2.4%	2.2%	2.3%	2.2%
12413	0.2%	0.2%	0.2%	0.2%	0.2%
12414	0.5%	0.5%	0.5%	0.5%	0.5%
13	15.8%	15.8%	16.8%	17.0%	17.0%
14	20.0%	20.1%	20.9%	20.8%	20.8%
134	3.3%	3.3%	3.5%	3.6%	3.6%
Stay home	19.3%	19.6%	20.5%	20.1%	20.4%

Changing the model population from 95B to 20B has considerable impact on the probabilities of the various chain choices as shown in Table 4-4. This illustrates that the model does indeed assign quite different choice probabilities to different population segments and thus the inclusion of the chain choice model in the TDM is justified.

The increase in the fuel price increases the stay home rates as noted, but otherwise results in little redistribution of chain choices. Income growth implies a slightly larger redistribution, with a decrease in the stay home rate as the predominant effect.

The following table illustrates the increase in the rates of people staying home, when the fuel price is increased from 95B to 95B+. The changes are conditional on car availability, the likelihood of staying home increases by 0.45% when no cars are available in the household. The mode and destination choice sub-models allocate the car and car passenger modes lower probabilities, when there are no cars in the household. The increase in the stay home rate is larger when the household has one or two cars available. This is in line with a priori expectations; a fuel price increase would be expected to have the greatest effect on the mobility of those who have a car.

Table 4-5. Stay home rates, 95B vs. 95B+

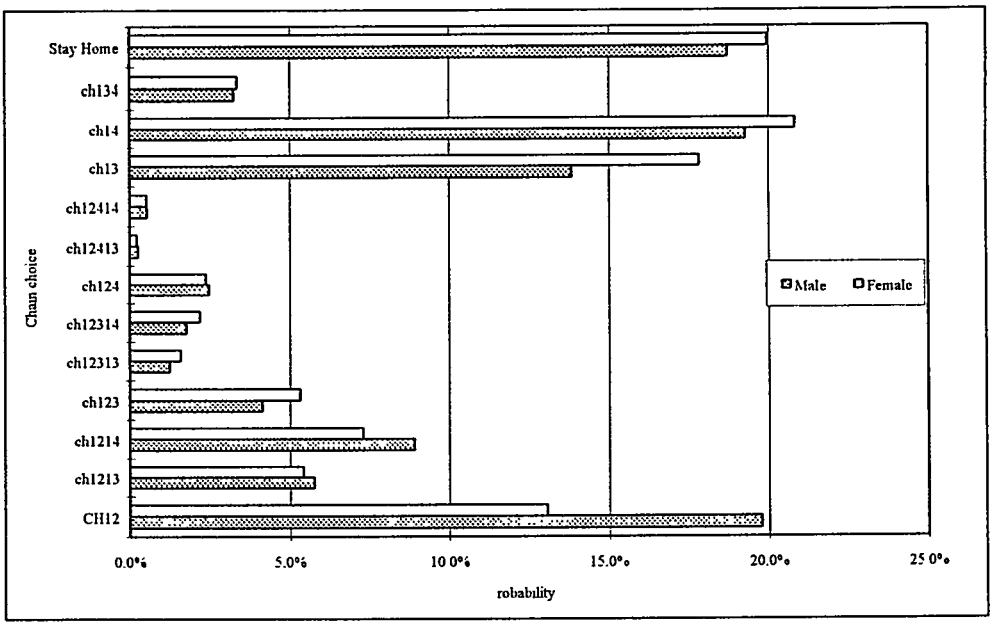
Increase in %	0 cars	1 cars	2 cars
95B+/95B	0.45%	1.25%	1.52%

Sex

The next figure illustrates the predicted chain choice probabilities, by sex, for the 95B scenario. The figure shows that the model incorporates significant differences between the sexes. In particular that men are more likely than women to go

to work only or to work in combination with a leisure purpose, where women are more likely to do errands only, go on leisure trips only or stay at home.

Figure 4-5. Chain choice probabilities by sex, 95B

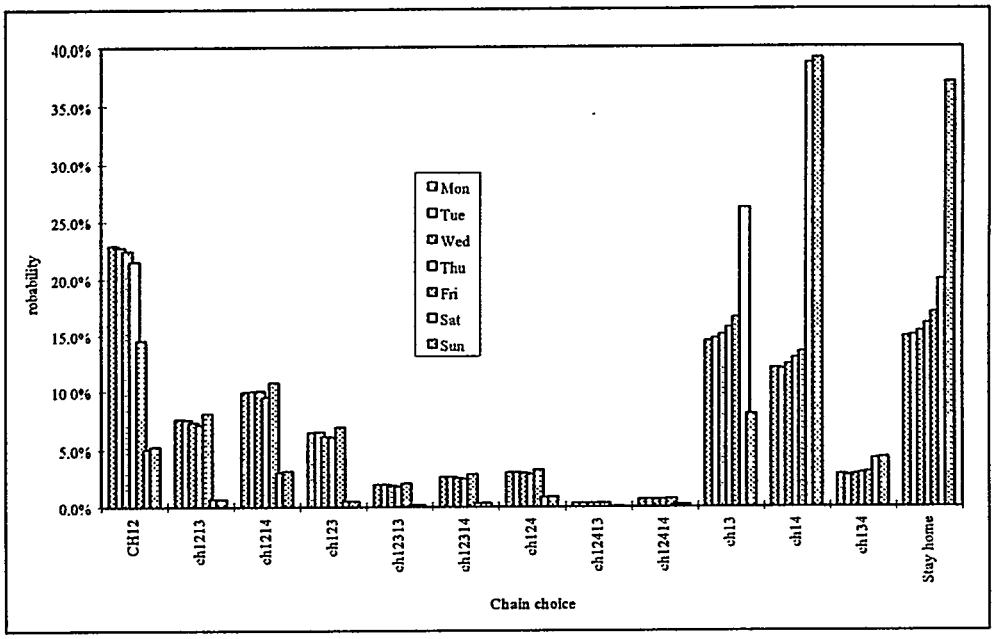


Weekday

Large differences in chain choice probabilities are observed over the week. For example, that the stay home rate is much higher on Sundays, that leisure tours only (chain 14) are much more likely during weekends, errand (shopping, chain 13) on Saturdays and that work tours are more frequent on weekdays. This is all as expected but illustrates how the model accounts for variation in many dimensions of the chain choice probabilities.

Figure 4-6 shows how the chain choice model distinguishes between days of the week.

Figure 4-6. Chain choice probabilities by day, 95B

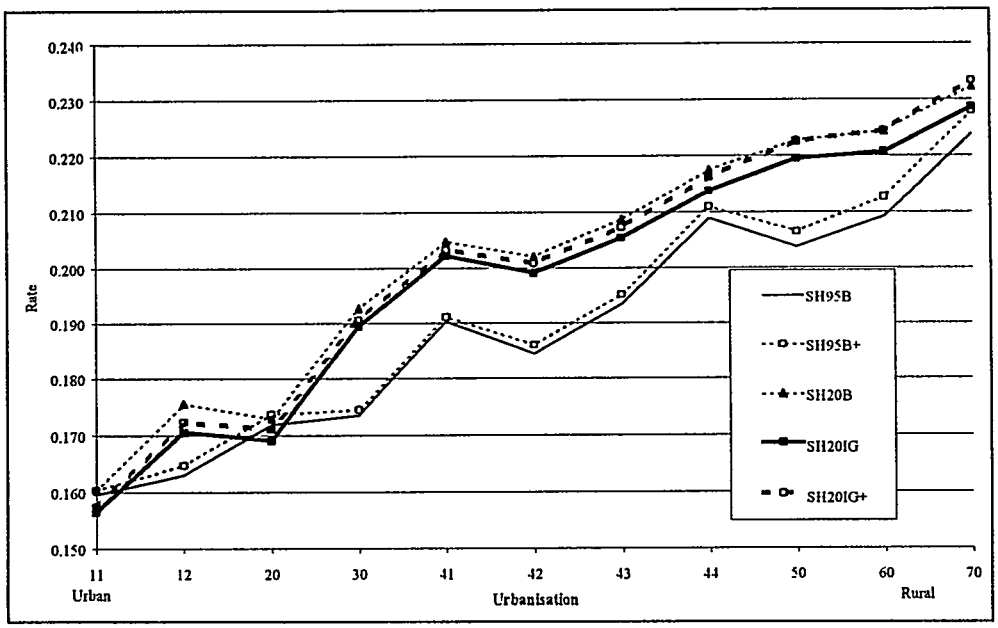


Urbanisation

The likelihood of staying home depends on urbanisation, as illustrated in the following graph. A change in income produces the most dramatic effect, increasing the stay home rate almost everywhere. The income effect is strongest at mid urbanisation levels, and smallest in Copenhagen and rural areas.

The effect of increased fuel price is small as noted but increases with decreasing urbanisation.

Figure 4-7. Stay home rates by urbanisation



4.2.2 Discussion

The model is able to account for variation in chain choice probabilities along a number of dimensions. The previous sections have illustrated a limited number of these; sex, weekday and urbanisation. There is a lot of variation in the choice frequencies, which will be important when evaluating different scenarios using PETRA. Thus, the inclusion of the chain choice model is justified since PETRA needs some kind of mechanism to assign individuals to the mode and destination submodels.

The differences in behaviour between different segments predicted by the chain choice model appear logical and reasonable. The responses to increased fuel prices and increased car availability are, however, very small.

One reason for the size of the responses, could relate to the use of the logsums as the accessibility measure. The logsums have some very attractive theoretical properties, that identify them as natural candidates for accessibility measures. However, the logsums are also indirect measures, that reflect not only the cost of mode and destination choice but also the attraction of the available destinations as well as differences in preferences between utilities.

A time constraint precluded a robust investigation into other possibilities. Although, any revision of the chain choice model would suggest that an investigation into other accessibility measures would be warranted. The logsum includes all the components that enter mode and destination choice. It is natural to look at the components separately. The components would be computed for each chain conditional on car availability and should include expected money and time consumption. A measure of attraction for each chain should possibly also be included, since it is attraction that makes people travel in the first place. However, attraction is reflected in the expected kilometres.

A further point in connection with the logsums is that the LoS variables for bus and train are weak, which is also indicative of weakness in the accessibility measures. This situation could be remedied by the collation of better network data.

4.3 Mode and destination choice

Eleven mode and destination choice submodels have been estimated for a similar number of tour types. In this section, the results from these models are presented, aggregated to the expected kilometres by mode. Aggregation is done by calculating the expected kilometres by mode for each submodel, conditional on chain choice and car availability, and then forming a weighted average of the distances using the chain choice and car availability probabilities as weights.

The mode and destination choice submodels have been estimated to match the choices observed in the TU data. For any particular individual, the travel diary has been transformed and then assigned to be an observation of a particular chain and corresponding tour types. The possibilities for choosing chains and tours are

somewhat restricted in the model. For example, a maximum of two tours is allowed and at most two destinations are allowed on any tour.

This implies that some of the trips actually undertaken are discarded from the observations. The mode and destination choice models only concern the trips that conform to the definitions. Roughly a third of destinations other than home are thrown away. Thus, the predicted travel demand only relates to the proportion of travel in the TU that is included in the TDM model.

4.3.1 Results

Kilometres by mode

The next table illustrates the expected kilometres by mode for each of the five scenarios.

Table 4-6. Kilometres by mode

Chain	95B	95B+	20B	20IG	20IG+
Slow	2.0	2.2	1.9	1.7	1.8
Car	15.5	10.9	15.5	17.4	12.6
CP	4.4	3.9	4.4	4.0	3.6
Bus	1.8	2.0	1.8	1.5	1.6
Train	0.4	0.5	0.4	0.3	0.4
Total	24.2	19.6	23.9	24.8	20.0

Increasing the fuel price from 95B to 95B+ decreases the distance travelled by car. The impact is most pronounced on car drivers, and less for passengers. Distances by all other modes increase. This is all in line with a priori expectations. A change in the population from 95B to 20B has only a minor influence on the results, apart from slightly decreasing the total distance travelled. Income growth increases the expected kilometres by car and decreases the distance travelled by all other modes as expected. This is true both for 95B and 20B. Finally, increasing fuel prices again decreases distances travelled by car, with the predominant impact on car drivers. It also increases the distance travelled by other modes, although less than the corresponding decrease in car.

By sex

The next two tables illustrate modal kilometres by sex. The two sexes exhibit the same reaction to the fuel price increase. Although, both before and after, women travel less by slow modes and as car drivers and more by bus and as car passengers.

In 95B, men and women travel almost the same total distance as car drivers and passengers. In 95B+, women travel more than men by car, 15.1 kilometres and 14.7 kilometres. This is perhaps somewhat unreasonable.

Table 4-7. Kilometres by mode, men

Chain	95B	95B+	20B	20IG	20IG+
Slow	2.1	2.3	2.0	1.7	1.9
Car	17.6	12.6	17.9	19.8	14.4
CP	2.4	2.1	2.6	2.3	2.0
Bus	1.8	2.0	1.6	1.4	1.5
Train	0.4	0.5	0.4	0.3	0.4
Total	24.3	19.5	24.5	25.5	20.2

Otherwise, men travel more by Slow and car as drivers, less on bus and as car passengers and the same as women on train. This holds for all scenarios.

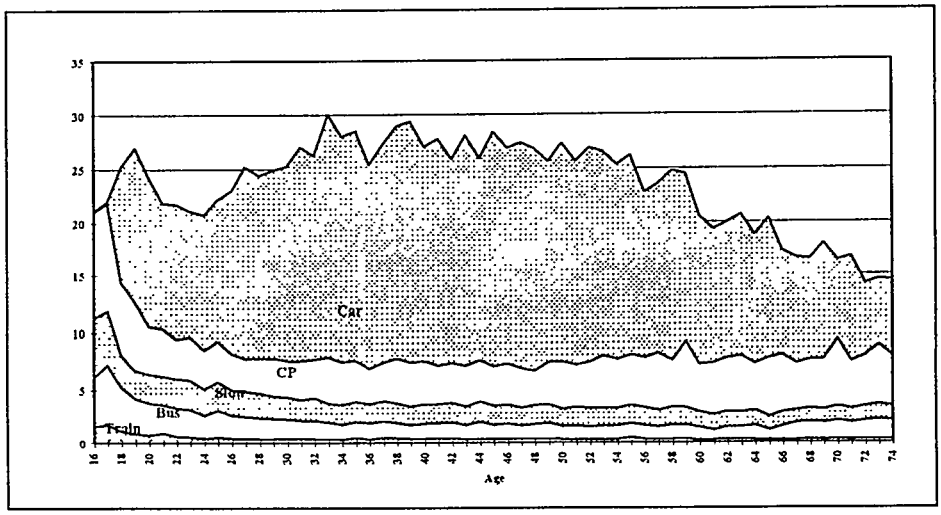
Table 4-8. Kilometres by mode, women

Chain	95B	95B+	20B	20IG	20IG+
Slow	1.9	2.1	1.9	1.6	1.8
Car	13.5	9.3	13.0	15.0	10.8
CP	6.4	5.7	6.1	5.7	5.1
Bus	1.9	2.1	1.9	1.6	1.7
Train	0.4	0.5	0.4	0.3	0.4
Total	24.1	19.7	23.2	24.1	19.7

By age

The following graph shows average kilometres by mode and age for the 95B scenario. The general pattern shown in the graph is the same for all scenarios. Car as driver begins at the age of 18, increases until the age of 30 and decreases again from the age of 50. Car passenger is most important for people under 18 - otherwise the kilometres as car passenger increase with age. The remaining three modes, slow, bus and train, are also more important when under 18, but use decreases with age.

Figure 4-8. Average km by mode and age, 95B



Income and sex

The next two graphs shows the expected kilometres by car for men and women. The income variable on the x-axis is 1995 net IP income grouped in 25,000 DKK intervals.

Note that men consistently drive more by car than women at all income levels. Note also that the reaction to a fuel price increase increases with income as car availability also increases.

Figure 4-9. Expected car km for men by income

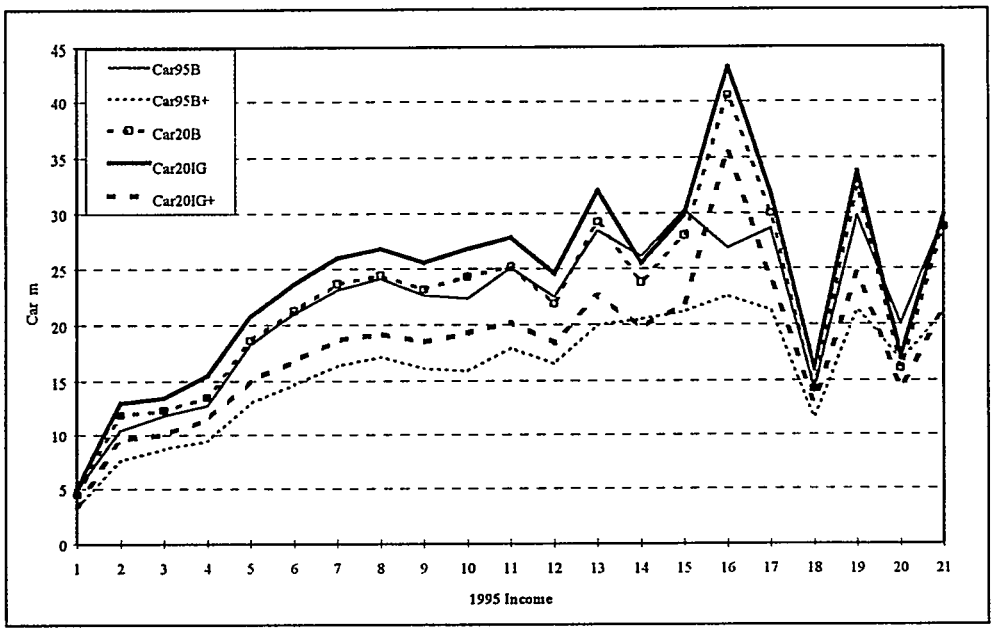
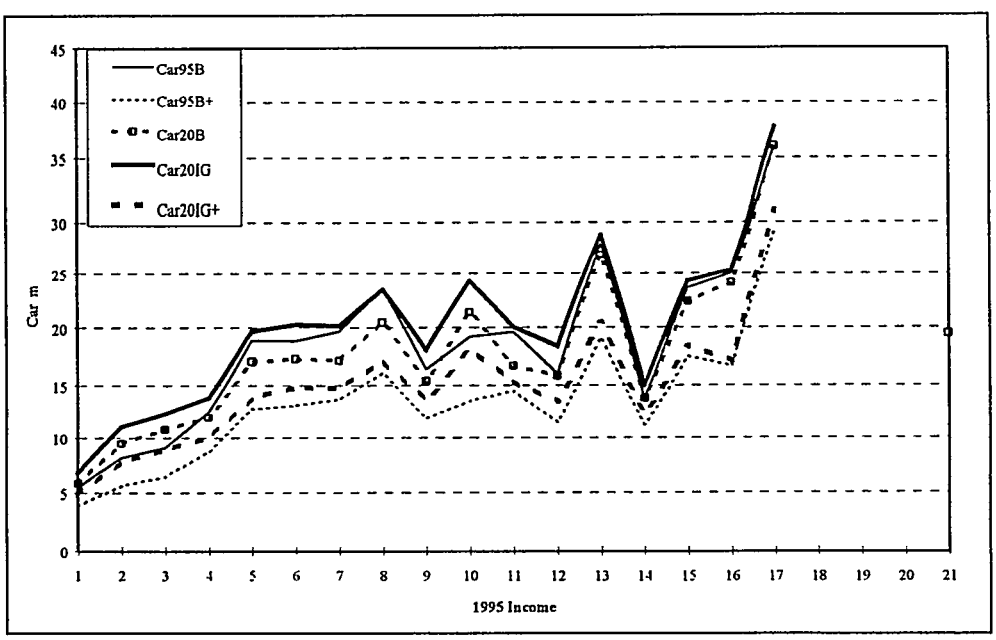


Figure 4-10. Expected car km for women by income



Urbanisation

The following two graphs show the expected kilometres by car as driver, and the expected total kilometres by the urbanisation variable. People in areas of lower urbanisation (higher urbanisation codes) are more heavily affected by the fuel price increase, both in 1995 and in 2020. People in the relatively affluent Copenhagen suburbs (codes 12 and 20) are less affected even though their travel demand is on level with those with codes 44-50.

Figure 4-11. Expected car km by urbanisation

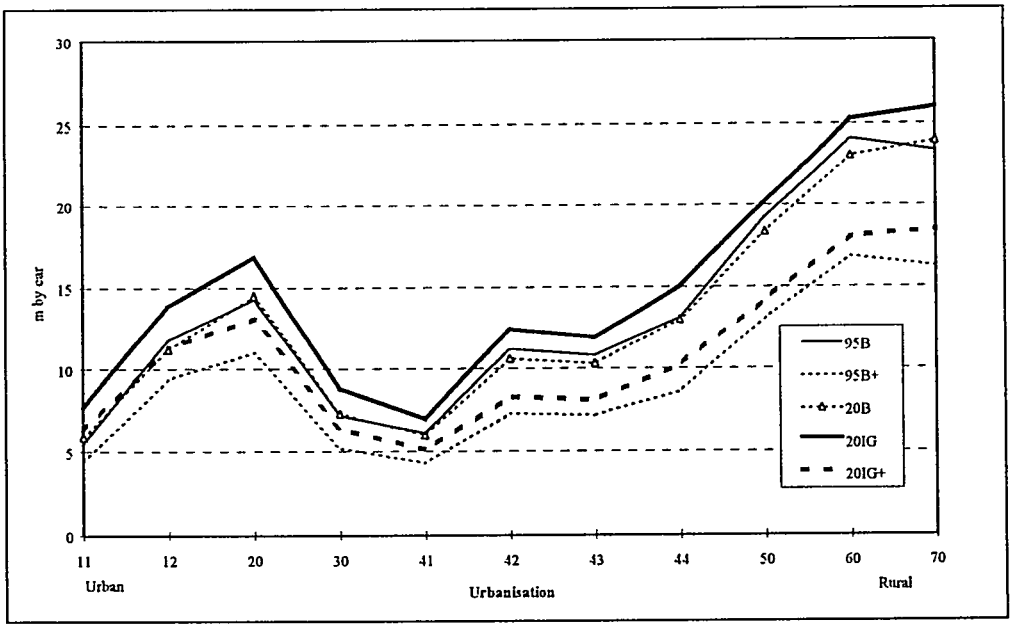
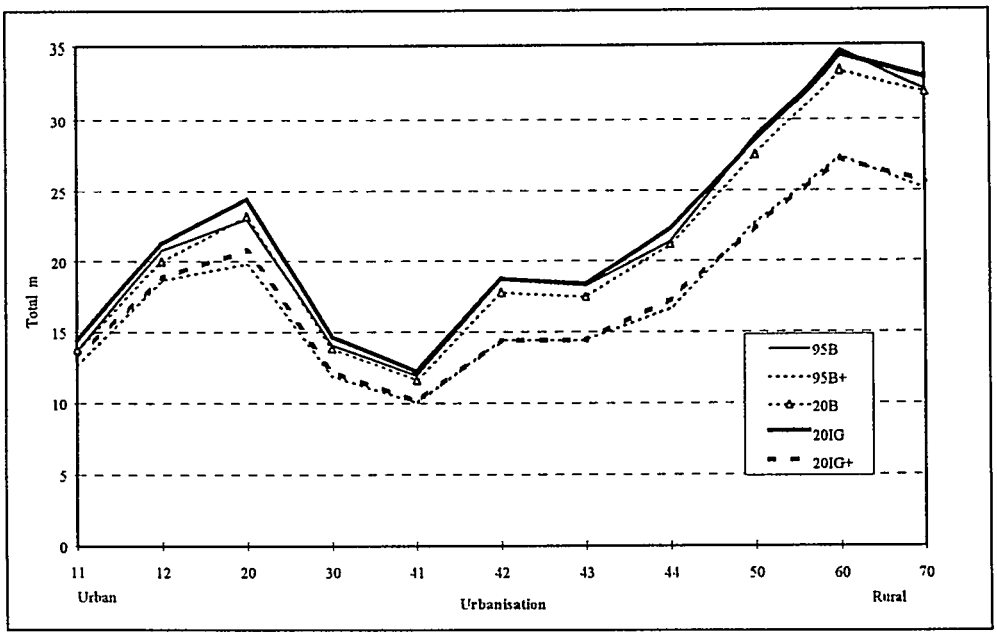


Figure 4-12. Total expected km by urbanisation



Car availability

The next table shows the expected kilometres by mode and car availability for the 95B and 95B+ scenarios.

The use of car, of course, increases with car availability and decreases with the fuel price. Households with 2+ cars are most affected by the fuel price. The CP mode is less affected by the fuel price. The mode is most used in 1 car households and almost as much in 0 car households. For CP, households with no cars are most strongly affected by the fuel price increase.

Use of all other modes decreases with car availability and increases with the fuel price. The use of non-car modes does, however, not increase sufficiently to offset the decrease in car use. Thus, the dominant effect of a fuel price increase is to decrease car use while mode shift is much less strong.

Table 4-9 indicates that the mode shift induced by the increased fuel price is highest in 0 car households and smallest in 2+ car households. In 0 car households, kilometres by car decrease by 2.2 while total kilometres decrease by 1.7. In 2+ car households both car and total kilometres decrease by 5.8.

Table 4-9. Expected km by mode and car availability, 95B and 95B+

	95B			95B+		
	0 cars	1 car	2+ cars	0 cars	1 car	2+ cars
Slow	3.8	1.7	1.2	4.0	1.9	1.3
Car	3.8	16.6	21.2	2.4	11.8	15.6
CP	4.8	4.8	3.7	4.0	4.3	3.3
Bus	3.4	1.5	1.1	3.6	1.7	1.2
Train	0.9	0.4	0.3	1.0	0.4	0.3
Total	16.7	25.0	27.5	15.0	20.1	21.7

4.3.2 Discussion

Where the fuel price increase did not have a strong impact on car availability and chain choice, it is seen to have a quite strong impact on the expected distances travelled by various modes. Thus, according to the model the primary reaction to a fuel price increase is to choose less distant destinations when travelling by car and the next reaction is to change mode. This tendency is strongest in 2+ car households while the mode shift is higher in 0 car households.

Increasing the fuel price leads to a decrease in car driver and passenger kilometres of 25.6% in 1995 and 24.3% in 2020. Car traffic levels decrease by 29.7% in 1995 and 27.6% in 2020. The implied elasticity of car traffic levels with respect to the fuel price is at the lower end of the spectrum of -0.3 to -0.5 found by Goodwin. It is, however, consistent with the range given by him when car ownership is assumed to be constant.

Thus, the fuel price elasticity of the mode and destination choice models is reasonable, while the fuel price elasticity of the car availability model is probably too

low. This was previously concluded in the section concerning car availability. Otherwise, the mode and destination choice models yield plausible results with the exception that female car use, car and car passenger, in one scenario turn out to be higher than male car use.

4.4 Emissions Calculation

4.4.1 Application of FLEET

The TDM yields a projected number of cars for each of the five scenarios. These numbers are input to the FLEET module which then projects the current car fleet by age and car type. Due to the poor quality of the car fleet data that is was possible to obtain, FLEET has been given low priority and is still in a quite rudimentary form. The only links between FLEET, EMIS and the TDM is the projected size of the car fleet passed on to FLEET from the TDM and the projected average petrol and diesel consumption figures passed on from FLEET to EMIS. Thus, EMIS is not does not distinguish between kilometres driven in cars of different vintages. Further, the 1995 fleet will be completely replaced in 2020. Therefore, only little of the information in FLEET is carried over to the forecasts presented here.

There is scope for improving emission forecasts by using the information in the TDM to produce calculations of the expected number of cold starts, kilometres driven and fuel consumption. Given that run times for the model are already around 18 hours and that this extension would increase run times by several hours it has been decided to postpone the inclusion of such calculations to possible future work on the model.

With these simplifications we get only two sets of fuel consumption figures from FLEET for use here. In the 1995 scenarios the car fleet will not have had time to change and fuel consumption figures are calculated for the hypothetical situation where the fleet has the same composition as today's new entrances. In the 20B and 20IG scenarios the same car fleet is assumed. Only in the 20IG+ scenario where fuel prices increase will the fleet have had time to change and separate fuel consumption figures are calculated for this scenario. The average fuel consumption figures computed are shown in the table below.

Table 4-10. Average fuel consumption from FLEET

Litres per kilometre	95B	95B+	20B	20IG	20IG+
Petrol	0.06185	0.06185	0.06185	0.06185	0.06177
Diesel	0.05054	0.05054	0.05054	0.05054	0.05053
Share of petrol cars	99.02%	99.02%	99.02%	99.02%	98.97%

The fuel consumption figures are applied to calculate emissions. PETRA does not assign cars to households (so far). This simplification is equivalent to saying that all households have the same average car.

4.4.2 Emissions from cars

The EMIS module takes the average fuel consumption figures from Table 4-10 and applies the emission rates given in the table below. This results in average emissions per car kilometre presented in Table 4-12. As the emphasis of PETRA so far is on behaviour we have assumed the emission rates to be the same in 1995 and 2020. In [20] they are the emission rates assumed for year 2010.

Table 4-11. Emission rates, 1995 and 2020

Emission	gram	Petrol	Diesel
CO2	Per litre	2410	2695
NOx	Per kilometre	0.42	0.38
CO	Per kilometre	6.08	0.49
HC	Per kilometre	0.9	0.11
Particulates	Per kilometre	0	0.09
SO2	Per litre	0.75	0.84

Source: [20]

Table 4-12. Emissions, gram per kilometre

Emission	95B	95B+	20B	20IG	20IG+
CO2	148.9	148.9	148.9	148.9	148.7
NOx	0.420	0.420	0.420	0.420	0.420
CO	6.025	6.025	6.025	6.025	6.022
HC	0.892	0.892	0.892	0.892	0.892
Particulates	0.005	0.005	0.005	0.005	0.005
SO2	0.046	0.046	0.046	0.046	0.046

Combined with the forecast of kilometres travelled by cars we obtain forecasts of the amounts of the various emissions.

Table 4-13. Total emissions from cars

Emission	95B	95B+	20B	20IG	20IG+	Unit
CO2	3,220	2,265	3,425	3,845	2,780	ktons
NOx	9	6	10	11	8	ktons
CO	130	92	139	156	113	ktons
HC	19	14	21	23	17	ktons
Particulates	98	69	105	117	85	tons
SO2	1,002	705	1,066	1,197	865	tons

In the first three scenarios, the calculated emissions are proportional to the total kilometres driven in cars. In the 20IG+ scenario the emissions per kilometre rates are slightly different and most of the decrease relative to 20IG is due to reduced travel by car.

4.4.3 Emissions from buses and trains

From [20] we find emission rates for the average passenger kilometre on bus and train. Again, the rates are those assumed for 2010.

Table 4-14. Emission rates for bus and train

Emission	Bus	Train
CO2	45.76	56.92
NOx	0.39	0.26
CO	0.15	0.03
HC	0.08	0.03
Particulates	0.02	0.03
SO2	0.01	0.12

Combined with the forecast travel demand for bus and train we get the following forecast of total emissions from bus and train for the five scenarios.

Table 4-15. Total emissions from buses and trains

Emission	95B	95B+	20B	20IG	20IG+	
CO2	147	167	156	127	142	ktons
NOx	1.124	1.269	1.196	0.984	1.080	ktons
CO	0.393	0.439	0.418	0.347	0.374	ktons
HC	0.218	0.244	0.231	0.191	0.208	ktons
Particulates	67	77	71	58	65	tons
SO2	92	112	98	76	95	tons

Again, emissions are proportional to distances travelled on bus and train. The changes between scenarios go in the opposite direction and compensate to some extent the changes in emissions from cars.

4.4.4 Total emissions

Combining the emissions from cars and public transport found above we find the following total emissions for the five scenarios.

Table 4-16. Total emissions

Emission	95B	95B+	20B	20IG	20IG+	
CO2	3,367	2,432	3,581	3,972	2,923	ktons
NOx	10.20	7.65	10.85	11.82	8.92	ktons
CO	130.66	92.05	138.98	155.89	112.95	ktons
HC	19.51	13.81	20.75	23.23	16.88	ktons
Particulates	165.30	145.88	175.82	175.29	150.30	tons
SO2	1,094.23	816.34	1,163.86	1,272.27	960.22	tons

Generally, the total emissions follow the emissions from cars up and down. Only the emission of particulates is almost the same in the 20B and 20IG scenarios.

5 Discussion and Conclusion

The previous sections have illustrated that the PETRA model system is capable of producing travel demand forecasts, that can be segmented in a number of ways. The possibilities for segmentation are by no means exhausted by the examples given. The differences in behaviour between different population segments predicted by PETRA are generally meaningful and credible. Thus, a significant ambition of the project has been realised. This level of segmentation is possible because of the disaggregate approach adopted. The resulting richness of information in the disaggregate data, results in increased precision in the forecasts.

However, it is also likely that a number of the identified problems also result from the quality of the data. Whereas mode and destination react as expected to a fuel price increase, and with plausible differences in reactions between segments, chain choice and car availability do not react as strongly as expected. The following section provides a number of suggestions for improvements. Generally, the problems are thought to be caused by the quality of the network data and the fact that the cross-sectional TU data set used only includes one year with no variation in fuel and car prices.

Three sets of weights have been calculated and are applied to the sample individuals to yield three different forecast populations. The reweighting of observations, together with the assumed income increase, result in significantly changed predictions. Again, the changes are credible, as are the different responses across segments, demonstrating the richness of mechanisms involved in forming the demand for travel that are preserved in the model system.

Thus, a very general conclusion on the PETRA project is that the project has illustrated successfully the feasibility of constructing a very detailed travel demand model that can be used for analyses in many different ways,

The model has yielded some more specific main conclusions: A very important conclusion is that the income elasticity of car ownership is probably lower than time series analyses otherwise have indicated. Population growth and structural change along with the remainder of the cohort effect imply a growth in car ownership that is independent of income. This again implies that the expected future increase in car use and ensuing pollution from cars is harder to control through vehicle purchase taxation than was previously thought.

A fuel price elasticity of travel by car of about -0.3 was identified. Being estimated on cross-section data it would be interpreted as a long term elasticity but since chain choice and car availability react little in the model, it is nearer a medium term elasticity. In previous work undertaken by COWI we have assumed a fuel price elasticity of car mileage of -0.30 to -0.38 when the fleet is kept constant and an elasticity of -0.40 when the size of the fleet is allowed to change. These figures will now be revised.

There are also some conclusions on the technical aspects of modelling travel demand. A new feature of the TDM in relation to previous transport models is the chain choice model. Although this model does not react as strongly as expected to the fuel price, it accounts for a considerable degree of the variation between individuals. It allows the division of mode and destination choice into a number of separate models for different tour types and these models have been shown to be very different. Thus, more variation between individuals is accounted for in this way than would have been possible if mode and destination choice were modelled for a number of travel purposes. Furthermore, the chain choice model allows dependencies between different travel purposes, for the simple reason that only one travel chain can be chosen in the chain choice model. In traditional models, travel frequency is modelled independently for a number of travel purposes. From this point of view the incorporation into PETRA of the chain choice model must be viewed as a success.

5.1 Future Developments of PETRA

PETRA has now reached a level where it can be used for actual policy analysis in a number of distinct areas. The present study has identified a number of areas, where the model system could be improved. It is expected that PETRA will be used for analyses on an on-going basis, and through such use, further areas might be identified where the system could be further improved or elaborated.

We believe that further development will substantially enhance the usefulness of PETRA, and a planned and prioritised upgrading of PETRA will undoubtedly have a more significant benefit to both PETRA, and the quality of the output, than making ad hoc amendments, as and when relevant issues arise.

The following represent a number of areas where the work up to this point has indicated a significant potential for improvement. The areas are given in rough order of priority.

Improved network data

The network data employed in the model are not perfect. The TDM employs two actual networks, for road and train, in addition to level of service variables for bus. Road distances and times for all modes except train are computed from the road network. The road network, delivered by DMU, is satisfactory at present but could be improved with further approximation to actual distances and speeds.

The data employed for PT are less good. Bus distances and speeds are computed from the road network which is acceptable, but could be improved by including real timetable data.

Level of service as measured by the number of departures is not well represented. PETRA uses the number of departures from each zone, but there is no link between the origin and destination zones. Thus, PETRA currently uses the number of buses stopping in A and the number of buses stopping in B to measure the suitability of using bus to get from A to B. This LoS measure does not perform very well in the model.

Using an actual bus network, the LoS measure would ideally be the number of buses going from A to B. Successful improvement of PETRA with such network data would allow analysis of the effect of improving the bus network on, e.g., mode choice.

Similarly, the underlying rail network is quite rudimentary. The TDM would benefit from a more detailed network and it is likely that the scope for analysing rail service improvements can be expanded.

More TU data

A weakness of the current TDM is that it is estimated on cross-section data for only one year. This implies that there is no variation in fuel prices and car prices. The influence of car prices on car availability is therefore tied to income in the model. Likewise, the effect from fuel prices to travel by car is closely linked with the time to different possible destinations and the attraction of these.

The inclusion of more TU data in the estimation database could allow a more robust estimation of particularly the influence of fuel prices. The parameters for cost and time are now quite correlated and this problem could be alleviated. At the same time the link between income and cost sensitivity could be further investigated.

Chain choice

There are a number of underlying issues in chain choice: Think of the differences in lifestyle between individuals of different age, sex, occupation, income, with no children or with children of different ages, etc., etc. Some of these differences are captured in the current model, but by no means all.

The model has been kept relatively simple due to the problems with the chosen accessibility measure as discussed above. A revised version of the chain choice model could be based on endogenous segmentation of the population into a number of lifestyle groups.

An interesting development in the theory of logit modelling [18] allows the estimation of models where individuals are assigned endogenously to different behavioural segments. The assignment takes place with varying probabilities according to socio-economic background variables rather than the usual exogenous segmentation where individuals are assigned to segments based on rigid rules.

The exogenous segmentation model could allow the model to show, for example, that one lifestyle group tended to choose mainly some chains with higher cross-elasticities between these while other groups had other preferences.

The current model is not well suited to handle this kind of segmentation. A revised chain choice model could test this structure and test the use of improved accessibility measures. The relative scarcity of observations of some choices, suggests that obtaining more data, as discussed above, would be of particular benefit to the chain choice model.

Cohort effects in mode and chain choice

There are observed differences between sexes in mode and chain choice. Women are more likely to travel as car passengers and more likely to travel for errand purposes. Some of this difference is probably due to differences in preferences rather than circumstances such as income. It could be hypothesised that the differences are smaller for younger generations and that they thus will diminish in the future for the population as a whole as a cohort type effect. This could be investigated in a further development of PETRA.

FLEET improvement

The FLEET model has the CCM as one of its components. The CCM distributes new car sales on 25 vehicle types. An on-going project by COWI for the Danish Ministry of Energy 97 Research Programme and the Ministry of Transport aims to build a substantially more detailed model for the choice of car. This is scheduled for completion in 1998, and the model is intended to include more than 100 vehicle types.

The project includes an SP analysis to gain insight into the factors affecting car choice. Primary factors of interest include those affected by policy; the mix between fuel prices, annual taxes and registration charges.

The replacement of the CCM in PETRA with this new model will allow for a much more precise analysis of vehicle choice, as influenced by taxation. It should also provide information on how the different costs of vehicle ownership enter the ownership decision relative to each other. This is currently a weak point in the TDM, as it is in the economic literature.

And more

At a later stage, the new car choice model could be replaced by a dynamic car ownership model, disaggregated to the household level, for the whole car fleet. It would be dynamic in the sense that the time dimension is explicitly included in household decisions to go in or out of car ownership, and whether to keep or replace an existing car. It would also include used car transactions.

Streamlined implementation

PETRA currently runs in ACCESS in conjunction with DOS programs. A scenario run takes more than 18 hours on a fast PC and the model databases occupy several gigabytes. No user interface has been programmed and the preparation of a scenario run requires modification of several ASCII files, creation of a new scenario database and sometimes calculations in separate spreadsheets.

The ease of use of PETRA can be enhanced through reprogramming in a lower level language, and run times could be substantially reduced. Reprogramming is necessary if the model is to be expanded as suggested above. There is a potential danger of errors when adjustments have to be made in several places for a scenario run. The variables can be collected in a single place. It may even be feasible to program an interface such that a user can run the model independently.

Emissions calculation

Emissions from cars with catalytic converters follow a pattern where a large part of the emissions occur when the engine is started until the converter is warm. Then follows emissions proportionally to the distance driven. Only emissions of some substances are more related to fuel consumption. Emission rates tend to increase proportionally to the total distance driven over the vehicle life as the catalytic converter gets worn.

In a reprogrammed version of the forecast model functions to calculate emissions directly at the individual level can be built in with the functions taken from the TEMA project [16]. It is also possible to build in such functions in the present version of PETRA but the already long run times would be increased by several hours.

6 Appendix

6.1 Licence Assignment

Licences

The year and the income level partly determine the licence holding status for the individuals in the model population.

The actual licence holding status is used for the 1995 Base population, and the licence holding rates are increased relative to the 1995 Base population for both the 2020 Base and the 2020 IG populations. Therefore, a number of licences are assigned to individuals in the two 2020 populations in the following way; First, COHORT is applied to give average licence holding rates for 2020. These rates are generally higher than the 1995 rates. The forecast rates enter the LICENCE model to give probabilities at individual level and the probabilities from LICENCE are used to assign licences in 2020 to individuals with no licence in 1995. We write the LICENCE probability of having a licence in, e.g., year 2020 as $P(l_{20})$ and the probability of not having a licence in 1995 as $P(0_{95})$.

For those individuals with $P(l_{20})>P(l_{95})$ we want to increase the sample licence holding rate and, conversely, we want to decrease the rate when $P(l_{20})<P(l_{95})$. At the same time we want to preserve as much of the original sample information as possible. That is, the licence holding status should be unchanged whenever possible.

When licence holding increases, $P(l_{20})>P(l_{95})$, everybody who has a licence retains it such that the licence holding status is unchanged. This amounts to $P(l_{20}|l_{95})=1$. Then by definition

$$P(l_{20}) = P(l_{20}|l_{95})P(l_{95}) + P(l_{20}|0_{95})P(0_{95}) = P(l_{95}) + P(l_{20}|0_{95})P(0_{95}).$$

Rewriting, we obtain

$$P(l_{20}|0_{95}) = (P(l_{20})-P(l_{95}))/(1-P(l_{95})).$$

Conversely when $P(l_{20})<P(l_{95})$, we let $P(0_{20}|0_{95})=1$ and then as above we obtain that

$$P(0_{20}|l_{95}) = (P(0_{20})-P(0_{95}))/P(l_{95}), \text{ and}$$

$P(1_{20}|1_{95}) = 1\text{-}P(0_{20}|1_{95}) = (1\text{-}P(0_{20}))/P(1_{95}) = P(1_{20})/P(1_{95})$.

Summing up, we assign licences for year 2020 with the following probabilities.

Table 6-1. Licence assignment probabilities

Case	$1_{95} = 1$	$1_{95} = 0$
$P(1_{20})>P(1_{95})$	1	$(P(1_{20})\text{-}P(1_{95}))/(1\text{-}P(1_{95}))$
$P(1_{20})<P(1_{95})$	$P(1_{20})/P(1_{95})$	0

Individual observations with no licence in 1995 are assigned a licence in 2020 using random draws with probabilities given by the above table.

6.2 References

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6.3 List of Abbreviations

ASC	Alternative specific constant
CP	Car passenger
Cph	Copenhagen
DMU	Danish Environmental Agency
DS	Danmarks Statistik, the Danish statistical bureau
GTC	Generalised travel cost
HH	Household
HP	Head of household as defined in [1]
IP	Interview person, the person for which the TU diary is made
LoS	Level of service in public transport
PT	Public transport
TDM	Travel demand model
TSA	Time series analysis
TU	The travel diary survey underlying the TDM
VoT	Value of time