APPLICATION OF DISAGGREGATE MODELS FOR A REGIONAL TRANSPORTATION STUDY IN THE NETHERLANDS

By:
A.J. Daly, Cambridge Systematics Europe b.v.
Laan van Meerdervoort 32, 2517 AL Den Haag
The Netherlands.

&
Ir. J. van der Valk, Drs. H.H.P.van Zwam, Rijkswaterstaat, Dienst Verkeerskunde,
Koningskade 4, 2500 EX Den Haag

INTRODUCTION

The paper gives a overview of the development and application of travel demand models for a major transportation study in the Western part of the Randstad conurbation of the Netherlands. This paper summarises the work of a large study extending over several years. More detailed results are published in the study Reports (numbers 1-11), some of which are written in English, others in Dutch.

The first chapter of the paper describes the aims and context of the study, which led to the choice of disaggregate modelling as the methodology for forecasting travel demand. The second chapter describes the analysis methods used to develop the models themselves. Chapter 3 presents some of the results obtained from the validation and application of the zonal models developed to analyse network design issues. Finally, chapter 4 gives the results of a number of analyses performed using the fully disaggregate forms of the models:analyses aimed at general policy questions.

1. ORGANISATION AND CONDUCT OF THE STUDY

The study described in this paper developed models for the Zuidvleugel ("South Wing") of the Randstad conurbation in the west of the Netherlands. The study was carried out by the Dienst Verkeerskunde of the Rijkswaterstaat, the Traffic and Transport Engineering Division of the Ministry of Transport and Public Works. Model development was the responsibility of Cambridge Systematics Europe b.v.. Several other agencies also participated in the study. In particular D.H.V. Raadgevend Ingenieursbureau and the Nederlandse Stichting voor Statistiek together were responsible for the home interview survey, for which advice was also received from the Centraal Bureau voor de Statistiek.

1.1. Context and Aims

Current model development for the Dienst Verkeerskunde is specifically designed to develop policy analysis methods on the one hand for forecasting traffic flows for strategic studies and on the other hand for predicting the transport effects of general policy measures (i.e. policies ,less specific to location).

In the first case, where flows must be forecast depending on alternative transport or land-use policies (e.g. construction of new roads, improvement of existing roads and land-use development plans) or on differing developments (e.g. spatial and/or socio-economic "scenarios" for the future), forecasts (in terms of traffic assignments) discriminating clearly between such changes must be available. Methodology for such discriminating forecasts must inevitably distinguish between different travel purposes and travel modes. Note that the personal and political valuations of different purposes and modes may well be different.

In the second case, the general policy measures under consideration must be able to be expressed in variables incorporated in the predictive models. Examples of such variables are the changes in the distribution of population or employment or variables directly related to transport such as travel times, overall parking restraints, public transport pricing measures or petrol tax changes. In these cases an assignment is not normally required and more important is the speed with which forecasts of the effects of policy with respect to mode choice, journey length, frequency, etc. can be evaluated.

Both types of model are required for applications in the revision of the Structuurschema Verkeer en Vervoer (National Long-Term Transportation Plan) and in the new Meerjarenplan Personenvervoer (Five Year Plan for Personal Travel). Current work on these planning systems is intending to apply models derived from the Zuidvleugel study.

1.2. Choice of Methodology

A range of alternatives were considered before it was decided to base the demand models for this study on disaggregate analysis. The context and aims of the study described in the previous section give the most important considerations behind this decision.

There were already in existence regional models based on data collected many years earlier (and in some cases in other countries). The development of a new model for a new area suggested an opportunity for estimation using up-to-date local data and using the best available methodology. The extent to which "state-of-the-art" models could be applied was of course limited by the need to produce a reliable working model without undertaking extensive fundamental research. Essentially this restricted consideration to models of the logit form.

The application of disaggregate methodology is particularly suitable for the tasks required in this study. Disaggregate models can be used, as in a number of previous studies, as the basis for zonal forecasting models of the classical type. Such models are suitable for preparing vehicle trip tables for assignment. Disaggregate models can also be used, through the technique of sample enumeration, to make more general forecasts for the whole area. Thus disaggregate modelling can be used to achieve both of the major modelling tasks of the study.

Given the diverse objectives of the study and the need to develop models responsive to many different policies over a wide area, it is inevitable that a large-scale model would be required. This large scale of development is unusual in disaggregate modelling, which is normally characterised by cheapness and simplicity since a model can be developed specifically for a single policy issue. In this case, however, so many issues were to be addressed that a comprehensive model system was essential.

2. MODEL DEVELOPMENT

This chapter describes the development of the disaggregate modelling systems used in the Zuidvleugel Study. The first section describes the data collected for model estimation and the second section the interpretation given to the travel data. The third section outlines the model structure. The two final sections describe the methods used for model estimation and for the aggregation procedure used to derive zonal versions of the models from the initial, fully disaggregate versions.

2.1. Data

The data from which the models were estimated came from three main sources. The home interview survey has already been mentioned; this survey was supported by transport networks and by a detailed set of data describing the characteristics of the zones into which the study area was divided.

The study area was defined to contain nearly all of the province of Zuid Holland and the western part of Noord Brabant. This area contains the cities of The Hague and Rotterdam and then to the south as far as the Belgian frontier. About three million people, nearly a quarter of the total population of the country, live in the area, which was defined to minimise the number of boundary crossings-that is, to make the area as much as possible self-contained.

The home interview survey was administered to a very carefully selected sample of approximately 3000 households living in this study area. The sample was selected to over-represent households of a particular interest to the study: long-distance commuters, car owners and public transport users. The methods used to select this sample are described in Report 4 of the study.

Separate transport networks were prepared for the highway networks, for public transport and for "slow" modes (walk, cycle and moped). Paths through the networks were built minimising generalised cost measures incorporating times and costs. Distance, time and tolls were measured along these highway network paths for input to the model estimation. For the public transport network, the various components (walking time, waiting time, etc.) were also measured along the paths. A special program was written to calculate public transport fares, in an attempt (which proved successful) to obtain good estimates of elasticities with respect to fares by measuring the fares accurately. For both highway and public transport modes, paths were built separately for morning peak, evening peak and off-peak conditions. For slow modes, however, only one set of paths was built, minimising distance, and distance was the sole measure of impedance for these modes used in model estimations.

The networks were constructed at two levels of detail. The locations of the households surveyed were coded to an accuracy of 500 metres, and for connections to the households this level of detail was employed. In other cases, however, locations were used at a zonal level of accuracy, so that the networks also had to be properly defined for this level of detail. In the event, the "home" end of trips was defined at 500 metres accuracy; the "other" end was defined only at zonal accuracy.

The final important data set was a collection of characteristics for each of the 319 internal and 77 external zones defined for the study. Such characteristics as employment and population were broken down into classifications of employment types and age groups in the population. Land use data was included, as was vehicle ownership, but data on driving licences was not available at this level.

2.2. The Unit of Travel: Tours

The purpose of the models being developed was to forecast travel for policy analyses which usually require the forecasts in terms of person-trips. For example, perhaps the most important policy analyses for this study are the traffic assignments which inevitably require as input vehicle-trips, or equivalently, driver-trips. Similarly, nearly all other analyses can exploit forecasts in the form of trips. The familiar four-stage Urban Transportation Planning models therefore use trips as their fundamental unit of measuring travel.

However, if consideration is given to the reason leading people to travel, the adoption of trips as a basic unit appears less satisfactory. The key point recognised by so many writers on the behavioural basis of travel is that, in the over whelming majority of cases, travel is a derived demand. People do not usually travel for the fun of it, but because their daily schedule requires them to perform some activity (work, shopping, etc.) which can only or can best be done away from home. It is eminently reasonable to suppose that the ultimate approach to predicting travel is therefore first to make some prediction of the acivity patterns of each person within a household, contingent on all the constraints that each person faces, and then to predict what travel is necessary to permit activities outside the home. This approach is however not yet feasible, since activity models are not yet sufficiently developed to form a basis for reliable travel forecasting.

It is nevertheless possible to take some note of fundamental research on activity patterns in the design of practical models, bringing the models one step closer to our best understanding of the behavioural basis of travel. This idea had two practical consequences for the models themselves: first, that a larger number of purposes than usual were separately identified and independently modelled; and second, that the units of travel were changed from trips to tours. The first change is simple enough in principle, and clearly allows more insightful modelling of, for example, social and recreational travel by treating them separately. The second change, however, requires more justification and explanation.

A tour is defined to be all the travelling between a traveller's leaving home and his or her next return. When an activity is performed away from home, in the majority of tours (83%) the traveller goes directly to the required destination, performs the activity, and returns directly home, thus making two "trips", in the familiar definition. For this majority of simple tours, the tour is therefore exactly the amount of travel necessary for a single non-home activity. It is reasonable to suppose that the traveller considers the total inconvenience of the tour in deciding whether, where or when to perform the activity and how the necessary travel (in both directions) should be performed. This direct connection between the characteristics of the tour and the travellers's decision concerning the activity means that we can expect more rational modelling at many points in the forecasting system.

In a tour model, non-home-based travel arises in the form of "detours" (an apt word) from the simple there-and-back norm. Given a series of destinations on a tour, it is often reasonable to label one of them as the "primary" destination and to treat travel to other destinations as being conditional on travel to the primary destination. This detour approach to non-home-based travel is clearly a simplification, but it seems a constructive first step to a comprehensive model. In this study, the primary destination was taken to be the workplace, if one of the destinations on the tour was a workplace (the usual workplace taking priority); otherwise the destination at which most time was spent was defined as the primary destination.

In addition to the improvements gained by including the whole tour in modelling the choice between alternative modes, destinations, etc., and the improved treatment of non-home-based travel, the tour basis gave the Zuidvleugel models a further important improvement over trip models in preserving the linkages affecting the whole tour. For example, mode choice was found to be constrained to be the same for most tours (97%) since a traveller leaving home by car or bicycle normally takes the vehicle with hime until he returns home, although switches between walking, public transport and car passenger are of course possible (1½%). Such constraints are very difficult to incorporate in trip models, as are time-of-day constraints (that, for example, a return trip must start a reasonable time after the outbound trip).

The discussion above summarises the rationale for the choice of tours as the basis for the Zuidvleugel models. More detailed information is given in Report 5 of the study and by Weisbrod & Daly*.

2.3. Model Structure

The scope of the modelling defined for this study was, as indicated, to predict frequency, destination and mode for personal travel for all purposes by the residents of the study area. The problem remained of determining the form and structure of model appropriate for these three decisions.

It was decided to use models of the "logit" form (with extensions) for all of the models within the system. The crucial assumptions on which this model is based are:

- the symmetry of the alternatives within the choice set**;
- that the choice set itself can be precisely defined;
- that the attractiveness of the alternatives can be properly specified.

Relaxation of the first assumption has been the subject of much successful research in recent years (see, for example, Manski and Westin***). The simplest method developed in that research allows limited relaxation of the symmetry assumption by defining logit models over subsets and groupings of the fundamental choice set. This nested logit model was applied extensively in the Zuidvleugel Study, as will be described.

Relaxation of the second assumption raises question of what alternatives are actually open to the travellers and the parallel question of how these can be predicted. These questions have led to the definition of models in which the choice set is randomly variable between different travellers. It is also possible to incorporate a commonsense determination of circumstances in which some alternatives are certainly not available to some travellers (e.g. car driving

* G. Weisbrod and A.J. Daly, "The Primary Destination Tour Approach to Travel Demand Modelling", Cambridge Systematics Inc. (1979) (unpublished).

** This assumption of symmetry is often described as the "Independence from Irrelevant Alternatives" (IIA) property. In a utility-maximising approach the assumption is more accurately characterised as that of "Independent and Identically Distributed" (IID) unmeasured components.

*** C.F. Manski and D. Westing, Theoretical and Conceptual Development in Demand Modelling, in "Behavioural Travel Modelling", Croom Helm London, 1979.

for children). For the Zuidvleugel Study, sophisticated structures with random choice sets were not applied, but absolute restrictions were applied wherever possible.

The third assumption is now also receiving more research attention. The variables included and the form in which they appear have been questioned and constructive experiments have been made. For the Zuidvleugel Study and important extension was made in the form of the attractiveness function, allowing a much better estimation of the parameters of destination choice models.

The various travel decisions to be modelled, for each purpose, were:
- frequency, i.e. making zero, 1,2,3, etc. tours in the survey day;
- destination, which was represented at a zonal level as a choice among the 319 internal and 83 external zones;
- mode, in which eight modes were recognised (as shown in Table 1).

The reasons leading to the choice of the model structure actually implemented are described in Report 1 of the Study. In general these decisions were taken on the basis of <u>a priori</u> expectations about the proper structure that had to be verified by subsequent empirical tests. Some minor modifications were made to the structures on the basis of the empirical findings.

The general model structure is shown in Figure 1. In the figure, the linking of models by a solid line indicates that the lower model is conditional on the higher model (for example, that main mode choice is represented as conditional on destination choice). The dashed lines indicate the incorporation of a "logsum" variable from the lower model in the higher. This variable is shown in the utility theory of the logit model to be the total expected utility from making a choice in a given choice set. It gives a kind of summary of the attractiveness of the choices at a lower level that is appropriate for inclusion in a model at a higher level. The utility theory further shows that the logsum inclusion can make the whole model consistent with a theory of utility maximisation.

The structure involving frequency models is somewhat unusual. It was found that the choice whether or not to make the first tour in a day for a given purpose was significantly different from the choice whether or not to make repeated tours for the same purpose. However, it did prove possible to model the choices of whether or not to make a further tour, when a given positive number (1,2,3...) had already been made, by the same model whatever the number of tours already made. The structure is a simple extension of the "ordered" logit model *.

The destination model is conditional on both frequency models in the sense that as many destination choices are to be made as there are tours. For all purposes other than work and education, destination and mode were combined as a joint model. In principle, this need not be seen as a structural change, since the joint model is equivalent to a nested structure with a logsum connection if the logsum coefficient is constrained to 1.0. In practice, however, the change is really structural, since the joint model allows simultaneous estimation of mode and destination parameters. This simultaneous estimation has important advantages of statistical efficiency that are not otherwise available with the present computer software, and (for these tour purposes) it was adopted for that reason.

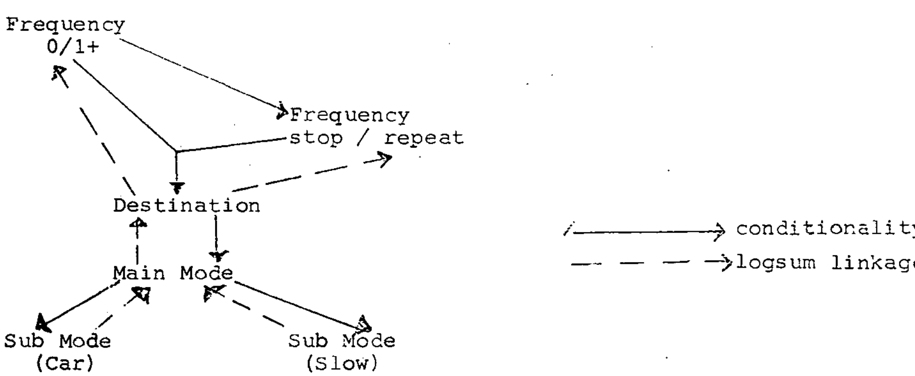
---

* Y. Sheffi, "Estimating Choice Probabilities among Nested Alternatives", Transportation Research, 1979.

Table 1: Modes Observed

Mode Group	Mode	Mean Tour Length (km)	Share%	Group Share%
Car	Driver	21.4	21.4	29.5
Pass.	household Car	22.1	6.3	
Pass.	other Car		1.8	
Public Transport	Bus/Tram	25.6	3.7	5.6
	Train/Metro		1.9	
"Slow"	Walk	3.7	32.3	63.1
	Bicycle		27.8	
	Moped		3.0	
Other	Various	--	1.8	1.8
Total	All	10.4	100.0	100.0

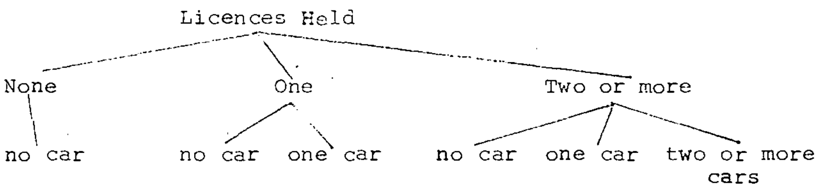
Figure 1: General Structure of Zuidvleugel Travel Demand Models
(for tours of each purpose)



The remainder of the structure of the travel demand models is reasonably straightforward, the unusually complicated mode structure reflecting the importance of a wider range of modes than is usual in industrialised countries.

In addition to the models of travel demand described above, models were also estimated of car ownership and driving licence holding for each household. The structure of these models is shown in Figure 2. In applying the models it is possible either to predict car ownership and licence holding using these models or alternatively to treat these as exogenously determined. Details of the car ownership and licence holding models are given in Report 9 of the Study.

Figure 2: Structure of Car Ownership and Licence Holding Models
(for each household)



2.4. Estimation method

The structural considerations outlined in the previous section allowed the specification for each tour purpose of a series of logit models, interacting with each other through the use of logsum variables as described. The remaining task in developing fully specified models was to determine for each model the variables that should appear in the attractiveness functions and the form they should take in those functions. In some cases it is clear for theoretical reasons that particular variables must appear in a specific form but in other cases the form that the variable should take is not clear *a priori* and information must be taken from empirical tests.

It was therefore necessary to make a large number of trials of models with alternative functional forms. For this project software was developed to facilitate the estimation of large numbers of logit models and their detailed analysis and comparison with each other. The opportunity was taken to complete a standard suite of software for logit modelling, which is described in Report 2 of the Study.

The usual form of the attractiveness function in logit models is linear, but for this study, it was considered important to allow one particular form of non-linearity, and the programs have been amended to allow this extension. The methods used for this extension of the methodology are described in a separate paper*.

In a study with so many zones (402), the estimation of a good destination choice model with all the zones present would be computationally infeasible. Fortunately it has been found that unbiased estimates can be made with a random sample of alternatives**. In this case, for efficiency, it was necessary to sample the "important" (i.e. nearby) alternatives more heavily than the more distant ones; this requires adjustments in the estimation process. Further sampling was done to reduce the number of slow mode tours appearing in the joint mode-destination choice estimations; again corrections must be implemented. These sampling procedures reduced the computational burden significantly.

2.5. Aggregation

In the models presented in the previous section all the available information was used at the highest possible level of detail in an at-

---

* A.J. Daly, "Estimating Choice Models Containing Attraction Variables", Transportation Research, 1982.

** D.McFadden, "Modelling the Choiçe of Residential Location", conference Spatial Interaction Theory and Planning Models, Bastad, Sweden, 1977.

tempt to obtain the best possible model. The applicability of these models for forecasting is clearly limited by the availability of data at the appropriate level of detail. One of the main applications of the model is, as mentioned, at an overall level in a sample enumeration procedure and there exists a suitable sample, with all the required data, in the home interview survey itself. For the other main application, to a classical zonal forecasting system, data restrictions play an important rôle.

The zonal data set that was available was unusually detailed but it was inevitable that some data items in the home interview were imperfectly represented, apart from the simple loss of accuracy due to averaging:

- some data (e.g. driving licences) was simply not available at zone level;
- some data (e.g. car ownership) was available only in a different form (total number of cars in zone, not information about the number of car-owning or multiple car-owning households).

For these reasons the form of the models had to be revised.

In moving from disaggregate to zonal level, there is of course a loss of information. This is particularly marked with variables such as age or sex which separate the population into groups with quite different behaviour but which have very little variation at a zonal level This problem was reduced by introducing market segments into the zonal models. For computational reasons it is undesirable to introduce too many segments, and a limit of 20 was fixed. Within the 20 segments it was possible to distinguish age, sex , licence holding and car ownership, thus greatly improving the accuracy of the zonal models.

Two alternative approaches are available for obtaining zonal models. The approach more simple in concept is to replace the disaggregate variables with their nearest zonal equivalents and re-estimate each model. The alternative approach is to take the view that the coefficients obtained in the most disaggregate version of the model are the best that can be obtained: modification to the model in order to use zonal level variables should therefore preserve these coefficients as much as possible. The disaggregate coefficients can be preserved by calculating a composite variable for each alternative which approximates as closely as possible the disaggregate attractiveness function, but using the zonal variables. The model should then be re-estimated using the composite variables.

For this study a combination of these approaches was used as appeared appropriate in the circumstances of a particular model. In many cases the replacement of disaggregate variables by their zonal equivalents was not straightforward, and in such cases the use of a composite function was unsatisfactory. It could, however, be used for a part of the utility function. In other cases, however, the theoretically preferable approach of a composite function turned out to be practicable, and it was then adopted.

Thus an entire system of zonal models was developed in parallel to the fully disaggregate model system. It was decided not to develop zonal models for slow sub-mode choice, because these models mainly function with detailed socio-economic variables, and because nearly all slow mode travel is in any case intra-zonal. The structure of the car ownership and driving licence models was also simplified substantially. A total of 33 models was developed (c.f. 40 fully disaggregate models). Both disaggregate and zonal travel demand models are reported in Report 7 of the Study.

2.6. Implementation

The sample enumeration and zonal model systems were implemented seperately. Both systems are documented fully in Report 8 of the Study.

The sample enumeration system was implemented in a specially written program using the most disaggregate forms of the models. The objective of this program is to permit rapid evaluation of a range of policy options, and it has been designed accordingly to run quickly and easily on the computer system available. The sample enumeration program is linked with other programs allowing the user to specify tables for detailed analysis of the policy. The tables may be expanded to study-area totals, and the sampling error is given along with the value in each cell of the tables.

The zonal system requires for its implementation matrix manipulation on a large scale. The zonal model system uses a specially written matrix management program as its basis. It is designed to be "friendly" to the user, but it nevertheless requires the provision and manipulation of sub stantial data sets.

3. AGGREGATE APPLICATIONS

As noted in the introduction, a number of the policy tests to which the Zuidvleugel Study was directed were concerned with network issues. In particular, the adequacy of the highway approaches to Rotterdam was in question in relation to changes in the rate of migration to North Brabant.

Because of the crucial importance of the relationship of total demand to capacity in resolving such issues, a model carefully validated to the total demand level (as observed on the roads) is required. Further, because of the need to obtain assignment throughout the study area a model must be available representing the travel of every household rather than a sample; i.e. a zonal rather than a sample-based model. The use of a zonal model again requires a careful re-validation, because the direct link with the home interview sample is lost and this interview data is no longer a wholly adequate basis for validating the model. Thus for two reasons validation plays an important rôle in the application of an aggregate model.

The first section in this Chapter describes the validation that was undertaken for the zonal Zuidvleugel model. The second section gives some details of the manner in which the model system was prepared for forecasting for 1990, by outlining the forecasts made for the "base case" development of network and land use. A final section describes briefly some experience that has been obtained with applications of the aggregate forecasts.

More details of these forecasts are given in Report 10 of the Study.

3.1. Aggregate Prediction Tests

The models developed in this study are intended for forecasting the effects of policy or secular developments at a future time. It is therefore not possible in principle to validate the essence of the model (responsiveness to changes) at the present time. Nevertheless it is possible to make tests of the reasonableness of the model's performance and a number of such tests were carried out.

The first series of tests concerned comparisons of model "predictions" for the base year (end 1977) with figures derived from the home interview survey. In principle such tests are simply confirmation that the models have been properly coded into the application programs and this is in fact an important check when dealing with complicated models. In practice there are several reasons why the estimated models could differ from home interview findings that could only be found by a subsequent check. For example, there could be:

- geographical or other variations in travel intensity not incorporated in the models;
- error filters (necessary for modelling) introducing biases;
- "other" modes (e.g. taxis and motorcycles) were excluded from the modelling;
- biases deliberately introduced into the home interview (which therefore appear in the models) and which are removed by expanding the home interview.

For these reasons it is always desirable to make a series of checks between model and home interview. In the case of a tour model such as developed in this study, comparisons are further necessary to deal with modal and geographical variation in non-home-based travel, which is not fully represented in the models.

The results of these checks were encouraging. For overall parameters, such as modal shares, tour lengths and frequencies, agreement was almost exact. For more local effects, there was more variation, but the model figures generally remained well within the confidence interval for the home interview survey. The conclusion was clear that the model reproduced rather closely the behaviour observed in the home interview.

Comparisons of model predictions with "independent" data proved more difficult. The aim was to make the main validation of the model at a screenline, the Hollands Diep, a major waterway to the south of Rotterdam, and roadside interviews and a train survey were held there. On analysis of this survey it became apparent, however, that the travel observed at the Hollands Diep was extremely atypical of the study area as a whole. The major difference was in the tour lengths: 95% of the Hollands Diep traffic was travelling more than 50 km, compared with 4% in the home interview. This naturally meant that much of the Hollands Diep traffic did not remain in the study area. Further problems arose with the definition of purposes and modes: nearly 10% of the Hollands Diep travellers were in a "car" holding 5 or more people. When these problems had been resolved, however, the difference between the model and the screenline survey was in the range of 15-20%. This difference is just what we should expect from a model based on a home interview survey, in which some travel is inevitably lost.

Because of these difficulties with the Hollands Diep survey, further comparisions were made on other screenlines around Rotterdam and later around Den Haag. Two principal difficulties arose here out of the fact that the screenline surveys had not been intended for this purpose but were part of routine surveys or from other studies. The problems were that it was difficult to separate out freight traffic, or, more importantly, external personal traffic from this data, which was largely collected with automatic counters. No complete cordon survey was made for the Zuidvleugel Study, and although of course freight and external traffic must be forecast in addition to the travel covered by the models described here, these forecasts were not available at the time the validation was done. Thus the comparisions were somewhat approximate. The general indication, however, was that a larger fraction of traffic (20-30%) appeared to be missed in the home interview than was suggested by the Hollands Diep survey.

Because of these results, intensive investigations were made of the correctness of both the home interview and screenline surveys. A number of errors were corrected in the screenlines, but although local weaknesses were found in the home interview survey, comparisons with other home interviews showed it to be on the whole sound. It was concluded that home interviews of this conventional type simply fail to record a fraction of travel and it is necessary to include screenline factors in order to match traffic counts. The factors were found to vary across travel modes.

In summary, however, although the validation process was less severe than could have been wished there was no reason to suspect that the models estimated contain significant unreliabilities.

3.2. Preparation for Forecasting

For network planning purposes the forecast year 1990 was chosen. In order to make forecasts for alternative network development plans for that year a substantial amount of information is necessary, particularly concerning the development of population and employment in the zones of the study area. In addition, forecasts had to be made of car ownership, driving licence possession, a demographic description of the population and changes in the (real) cost of travel.

For forecasting the development of population and employment, the very real difficulty was encountered of projecting migration rates. The study has been started with the particular aim of predicting traffic flows caused by the high rate of migration from the Province of Zuid Holland to the Province of Noord Brabant. However during the development of the study it appeared that the rate of migration was decreasing rapidly. At the time that land use data for the forecast year had to be collected land use authorities in the study area were uncertain about the expected migration. Two sets of land use data were therefore prepared in order to investigate the consequences for traffic flow and highway capacity of the migration assumptions.

Car ownership and driving licence forecasts were initially derived from the forecasts made (respectively) by Beukers and van der Broecke. Subsequently, however, forecasts became available from the models developed from the Zuidvleugel data**. These models gave confirmation of the overall trends reported by Beukers and by van der Broecke. In addition they allow zonal variation and detailed responses to scenarios and to policy or network changes to be calculated automatically. The most recent studies give no reason to question the forecasts that have been made.

Demographic forecasts are used by the model to represent the broad diffences of behaviour between six different population groups:

- children (5-11 and 12-17);
- working age adults (men and women);
- retirement age adults (men and women).

Reasonably reliable forecasts for the expected distribution of the population over these groups could be derived rather more easily than the employment forecasts.

---

* B. Beukers, advice note, Het Wegencongress, 1979.
A. van der Broecke, Rijbewijsbezit (Driving licence possession) in Nederland, Report, 1979.

** Described in Report 9 of the Study.

Estimated developments in the "real" costs (i.e. discounting inflation) of car and public transport travel are also required. Obviously such estimates are extremely difficult because of their dependence on international and internal economic and political changes. As an initial assumption the real costs for 1981 are assumed to be appropriate for 1990. Sensitivity testing is essential to determine the extent to which forecasts of traffic depend on these cost forecasts, and has been carried out with the disaggregate model set (see chapter 4).

Appropriate networks for 1990 were also prepared. The highway network for that year was based upon the National plan for the middle to long term: the Rijkswegenplan 1982. It was felt considering the annual budget for road construction that the network belonging to phase 1 of the Rijkswegenplan was a relevant base for the study. Policy following to the local transit authorities including the Dutch National Railways for the study area an approriate transit network was adopted. The slow-mode network was assumed to the unchanged between 1977 and 1990. For these networks the required level of service data were derived for the future year. After preparing this input the forecasts could be made.

3.3. Aggregate Forecasting

Aggregate forecasts were made initially for the networks planned in the Rijkswegenplan 1982, using the low-migration scenario to define land-use development.

In making the forecasts, a "balancing" process was necessary to ensure that the number of work tours arriving in each zone should be consistent with the employment in that zone. It can be seen from the structure of the models described in Chapter 2 that the models as estimated do not necessarily maintain this consistency and an amendment was made to the implemented models to achieve the appropriate balancing. The results obtained by this procedure were judged to be satisfactory.

The total results of the aggregate forecast for 1990 showed a 32% increase in car traffic (relative to 1977) and a 4% increase in the use of public transport. The total number of tours by all modes showed an increase of a 8,5%. The increase in car traffic can be divided into an increase in the number of tours of 21% and an increase in the average tour length of 11%.

These forecasts were judged to be very reasonable, and consistent with the mobility growth in the National long term Transportation Plan. Also the traffic forecast for the main routes, especially those between the Rotterdam area and Noord Brabant, appeared to be reasonable.

The results of these forecasts were therefore applied to study several network issues. Among these are some of the most important motorway issues in the Netherlands:

- the function and design of the new motorway A4 between The Hague and Rotterdam and the A4 in Noord Brabant;
- possibilities for increasing the capacity of the Nieuwe Waterweg crossings in and near Rotterdam;
- layout of intersections of the N57 in the Voorne Putten area;
- the effect of the new A58 south of Breda.

Other analyses were also made using traffic assignments derived from the Zuidvleugel models.

4. FULLY-DISAGGREGATE APPLICATIONS

In addition to network design issues, the Zuidvleugel Study was intended also to address more general policy issues. The means by which this was achieved was through the implementation of a "Sample Enumeration" procedure.

The technique of sample enumeration has been in use for several years*. Simply, it involves the successive application of the models to each person (or each household) in a sample. In the applications described here, the models used were the fully-disaggregate models, and the samples of persons (or households) were taken from the home survey**.

The characteristics of sample enumeration are that it allows very quick and cheap*** yet detailed analyses to be made of policies or developments that can be expressed simply. Because sample data is used from a home interview, rather than zonal data, a wide range of tabulations of the results is possible. The limitation of the technique is essentially that a representative sample must be available to evaluate any given policy. In this study, the sample used were taken exclusively from the home interview, so that applications are limited to the base year, to the study area, and to the uniformity of coverage of the study area given by the home interview (inadequate for network design purposes).

The output of the sample enumeration system (forecasts for each individual) can be expanded to give study area totals by applying expansion factors in the usual way. Tabulations of these figures are then made to show the impact of the policy under test on sub-groups particularly affected by the policy.

To apply a sample enumeration usefully, it is necessary to be able to express the policy under test in terms of the model variables. While the Zuidvleugel models include a wide range of variables not usually found in travel demand models, it must be noted that not all policies can be tested.

To show the flexibility of the methodology, five policy evaluations and a scenario of economic development are presented in the following sections. Finally, to illustrate the advantages that the speed of sample enumeration gives, a policy evaluation is presented that requires iterative application of the models.

As a general conclusion on the disaggregate policy tests it can be said that the predicted changes in terms of shifts in frequency, distribution and mode split per purpose were very reasonable. More details are given in Study Report Volumes 10 and 11.

4.1. Policy: Increase Parking Costs

This policy postulates a doubling of the parking costs in central areas of cities. The policy was tested for Rotterdam. A split was

---

* Atherton and Ben-Akiva, Transportation Research Record, 1976.

** More recent work has used other samples, even of "artificial" households.

*** For the Zuidvleugel System, estimates of 20 minutes and ƒ120,= (Netherlands Guilders) have been made.

made between inhabitants of the city of Rotterdam and people living in the rest of the study area. The results were as follows:

- overall shifts were observed from car modes to other modes, greater for other purposes than for work and education;
- for residents of Rotterdam the shifts were primarily to slow modes, for residents of the surrounding areas primarily to public transport;
- there was a substantial shift to other destinations for purposes other than (obviously) work and education for people from outside Rotterdam, for the inhabitants of Rotterdam the shift to other destinations was clearly less;
- the total number of tours hardly changed.

4.2. Policy: Traffic Management Measures

This policy represents measures to reduce car traffic in a city with the intention of improving traffic safety and reducing pollution and other disruption of the environment. The policy tested was an increase in travel time by car by 15% in the city of Rotterdam. This increase can be realised, for instance by adjusting traffic light settings, introduction of one way traffic, enforcing detours etc.

The effect on the total number of tours by all modes was very slight. The number of car tours decreased (by about -3%), specially for the purposes shopping (-7%), social (-3%) and recreation (-14%). For these purposes there was a clear shift from car to slow modes, especially walking.

4.3. Policy: Petrol Price Changes

This policy postulated a doubling of the petrol price, more with the intention of investigating the elasticity of travel behaviour than of evaluating a realistic policy. The policy was tested for the whole study area.

The results showed a 14.5% reduction in car traffic, varying by purpose, and the use of transit increased by 5.5%. The average tour length was reduced by 7.7%, but the total number of tours made scarcely changed.

4.4. Policy: Public Transport Fare Changes

In this case, rather than a single policy change, a series of different levels of public transport fares was evaluated, ranging from 0.5 to 1.5 times the 1977 fare levels. The policy was tested for the whole study area.

Once again the results showed considerable variation by travel purpose. Work travel had a direct price elasticity for public transport trips of about -11% (calculated on changes of ± 20%), whereas the other purposes had much higher elasticities, giving an overall elasticity of -49%. For most purposes changing transit fares affects only in a minor way the use of cars and much more strongly the slow modes.

4.5. Policy: Improve Accessibility of Workplace to Public Transport

This policy was intended to show the potential changes that could be achieved in mode choice by encouraging the development of workplaces near public transport services. This policy would be course be effective only over a longer term than that for which the home interview could be taken as representative. The policy postulated a halving of the walk times from the terminal point of the public transport journey to the final destination.

The policy was tested only for home to work travel, and showed a 5.7% increase in public transport use. The use of car for the work purpose diminished very slightly (-0.5%), the decrease for slow-modes was somewhat larger (1%).

4.6. Scenario: Economic Depression

It is also possible to use the sample enumeration method to show the impact of developments outside the control of transport policy. In this case the intention is to indicate the impact of severe economic depression on car ownership.

This sombre view of the future is represented by specifying that total employment will decline by 10%, and that this decline will be from unemployment in the building and industrial sectors. Within households it is assumed that many multiple worker households will lose one job and a few single worker housholds will lose that job. Further it is assumed that incomes will decline but that car costs will increase.

Implementation of this scenario requires that zonal and household level data be altered. Total zonal employment was decreased by 10% in those zones with sufficient building and industrial employment which was building and industrial, and was descreased by the fraction of total employment which was building and industrial otherwise. A 40% random sample of multi-worker households had the number of workers decreased by 1 and 2% random sample of single-worker households had the number of workers set to 0. Household income was reduced by 10% and car costs were increased by 15%.

The results of the evaluation show a 6.3% overall decline in car ownership, split almost equally between a reduction in two-car-ownership and an increase in non-ownership. Driving licences were also predicted to undergo a decline, but rather less.

4.7. Policy: Taxation Shift

To illustrate the combined use of the car ownership and travel demand sample enumeration programs it was decided to test the effect of the elimination of tax on car ownership and its replacement in government revenue by increased taxes on petrol. Calculation of the appropriate petrol tax increase involved some complication because there will be a reduction in the number of kilometres covered by an average car together with a possible increase in the number of cars.

To deal with this complication it was necessary to use both programs iteratively to converge on an appropriate value for the petrol tax increase. Fortunately with a sample enumeration program this approach is feasible, and in two iterations a reasonably close approximation was found. Additional iterations could be made to achieve a better solution, but for this illustrative evaluation this was not considered necessary.

The ownership tax for the cheapest common car (1977 basis) was taken as ƒ235,= per year, representing 8.3% of the total ownership cost (A.N.W.B. data for a Citroën 2 CV). The price of petrol was ƒ1,08 per litre, which was increased to ƒ1.43 for the policy evaluation.

The results show the main consequences of the policy as a 1.7% in-

crease in the number of cars, but decreases of 2.5% and 4.4% respectively in the number and average length of car driver tours. Negligible change in the number of licences is predicted for this policy. More detailed analysis of the changes in car ownership shows that two thirds of the increase comes from the purchase of second cars.

Calculating the revenue effects requires the additional information that the ownership tax averaged ƒ345,= per year over all cars in 1977. Elimination of this tax implies a revenue loss of ƒ272.8 million for the Zuidvleugel area. The additional tax collected on fuel is collected over a total kilometrage reduced by 6.3%, thus implying a revenue gain of ƒ271.5 million.

The figures given here rely on a number of approximations and simplifications, and are to be seen only as broadly indicative of the potential of the methods.

5. CONCLUSION

The requirements of the planning work at the Rijkswaterstaat indicated a need for a particularly flexible model system for the Zuidvleugel area. These requirements were met by basing the forecasting on disaggregate models.

A comprehensive model system was developed covering all aspects of personal travel. The Zuidvleugel models are the most advanced and complete system of disaggregate models yet developed.

A series of applications to network issues were made using the zonal forms of the models, which were carefully validated to observed traffic flows. The results obtained from these forecasts are most satisfactory.

Further applications to general policy issues were made using the fully-disaggregate forms of the models. Again very satisfactory results were obtained, the speed and cheapness of the techniques allowing a wide range of policies and scenarios to be tested.