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STOCKHOLM MODEL SYSTEM (SIMS): APPLICATION

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Abstract

The personal travel Stockholm Model System incorporates interactions within the household, integration of decisions concerning trip chaining, joint choices by separate individuals and treatment of constraints on travel behaviour. The model system is now in use for strategic and short term planning. The model system, its implementation and applications are described in this paper.

Prize

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BACKGROUND

Transportation models have been used in Stockholm for many years in evaluating transportation projects (Algers et al. 1979,1987). Most models had been limited to work trips, and dealt mainly with mode choice. This was a severe constraint in the evaluation of projects, because many of the effects may be more important for other trip purposes than work trips. In many cases, effects like changes in trip distribution and trip frequency may be very important but cannot be handled with the present models. Politicians also needed a more detailed analysis of distribution effects.

Therefore, planning authorities in Stockholm started discussions on the need for a more comprehensive model system in the late 1970's. The discussions went on for a long time, but decisions were finally taken and the project started with a travel survey in 1986 and 1987. The implementation work was finalised in October 1995. In this major upgrade of the Stockholm model system, the breadth and complexity of the planning issues and social and spatial developments made it necessary to consider several improvements to current modelling practice. The complexity of these improvements contributed significantly to the lengthy time span from the start to completion of the new model system, and affected the estimation phase as well as the implementation phase. It has, however, been possible to put parts of the model system into use before the completion of the whole model system. The objective of this paper is to describe the model system, its application procedures and some results from it (excluding the last implemented model for social trips).

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SCOPE OF MODELLING

Need to represent behaviour

The consequences of various transportation projects affect the travel behaviour of the individuals by changes in time, cost, etc. The individuals respond to these changes by changes at various choice levels—at the levels of mode and destination choice, and at the level of frequency choice. This has been recognised for a long time (Ben-Akiva and Lerman, 1985), and has also been taken into account in, for instance, applications of disaggregate nested logit models that allow for linkages between the different choice levels (Ruiter and Ben-Akiva, 1977; Daly et al. 1983). Such models have not, however, been estimated for the Stockholm region before. Because of the linkages between the levels of the model, the system is called the Stockholm Integrated Model System: SIMS.

There are other possibilities for the individuals to adapt to changes in the transportation system than at the choice levels mentioned above. One example is a shift of car use between the different members of the household, which might be the effect of an area licensing scheme. Another example might be a shopping trip, which can be assigned by the household to other household members as a consequence of a price or trip time change, affecting accessibility for different household members. A third example would be to substitute a home based trip by a second destination on the work trip between work and home. A change of travel times or costs may make it relatively easier to carry out shopping on the way home than as a home based trip. There are also various constraints that limit adaptation possibilities, such as the availability of the family car and working hours.

To be able to consider the different possibilities of adaptation to the effects of various policies, they have to be modelled explicitly. There is a clear need to design the forecasting system to model explicitly the mechanisms of travel behaviour. The Stockholm model system should therefore represent a step in that direction.

Scope of modelled behaviour

The requirements sketched out above for the model system are very challenging. The model must not only allow the testing of a wide range of policy measures, but also incorporate a rich description of travel behaviour. This implies that the model is necessarily large and complex, presenting problems both for estimation and for implementation. However, once these problems are solved, the planning instrument thus obtained will have an exceptional range of capability.

An important component of the policy packages to be considered with the aid of this model is infrastructure planning. The planning of infrastructure implies that a relatively long planning horizon must be used, perhaps 20 years. Medium to long term planning in turn implies that the models must be capable of predicting travel behaviour substantially different from what can be observed today. New housing and employment areas will spring up, and the links between the existing areas may well change substantially.

These fundamental changes in travel patterns require the model to be capable of constructing a complete synthetic picture of future travel. While information on existing behaviour should be used as intensively as possible, it is necessary to construct a complete picture of travel frequency and trip distribution as well as the shorter-term choices such as mode and route choice. Thus the Stockholm model system necessarily includes all of the components normally found in the classical "four-stage" planning models.

A further aspect of travel behaviour—also included in the model—was car ownership. It is necessary to incorporate car ownership into the modelling of other aspects of travel when travellers take their car ownership decisions jointly with decisions about other aspects of travel. At least as regards travel to work, this joint decision-making is plausible a priori and was shown to be important by the empirical results. For consistent prediction of travel, it is necessary to predict car allocation within the household as well as car ownership.

A key difference between the Stockholm model system and those developed in other areas is the degree of interaction that is allowed for in the system. The interaction between household members in the allocation of the car (or cars) owned has already been mentioned. In addition, interactions are modelled in the choice of destination, taking account of detours on the home-work journey to business, shopping and other secondary destinations and interactions are modelled between household members in the choice of which members are to do the shopping. Of course, other interactions of importance can be postulated within a household's travel patterns that are not usually incorporated in travel demand models, but it was felt that these interactions were the most important that could be reasonably be incorporated in a practical forecasting system.

The household behaviour that is represented in these models is treated as choice under constraint. That is, the household and its individual members are represented as choosing among a number of alternatives that are available for the particular aspect of behaviour covered by each model. Some alternatives are excluded for various reasons: they involve walking too far, they are too expensive compared with the household income, they are excluded by other choices (such as not buying a car), for instance, or they would take too much time, given the other commitments of the individual or household.

Thus the model system represents a large number of interdependent choices made by households and their members. A specific feature of the modelling is that the choices are made among discrete alternatives. The structure of the system for different travel purposes varies to take account of the varying aspects of importance in each case. For example, mode choice for the work journey is integrated with car ownership, but it was not felt reasonable to expect a strong influence on car ownership arising from other travel purposes.

Development of the population

Included in the model system are a wide range of interactions among household members, while many socio-economic variables are also incorporated. It is therefore necessary to make forecasts of the development of household structure and the other relevant socio-economic variables. These forecasts were made by the technique of "prototypical sampling".

Simply, prototypical sampling works by modelling the changes in the distribution of specified categories of household in the population by maximising the fit to a number of simple "target" figures. Target figures are defined using commonly-available statistics such as population by sex and age group and employment rates. These statistics can then be used to determine the changes that can be expected in the more complex household category specifications. Prototypical sampling has been applied in a number of previous studies, including the Netherlands National Model (Gunn et al. 1987).

For this study, the technique was extended to cope with the circumstances of data availability in Stockholm. Population data and forecasts existed for the zones to be used for SIMS, but household data could be provided only for aggregations of those zones, requiring a two-stage application of the prototypical sampling procedure. Segmentations of the travelling population were defined, varying by travel purpose, which allowed as much as possible of the socio-economic variation in behaviour found in the modelling to be represented in the forecasting system. The number of segments per purpose varied from 11 to 420.

Application of the procedure to the base year (1986/7) showed that it was possible to match the zonal targets with good accuracy, using a prototypical sample collected over the whole study area. Future-year applications also give plausible results.

Form of the choice models

The representation on a large scale of complicated sets of behaviour such as those proposed for the Stockholm model requires a model form that is capable of representing the full interactions that are required to be studied while not imposing too great computational requirements either in estimation or in application.

To balance these competing requirements, it was decided to use models of the generalised tree logit form (Daly, 1987). Models of this form allow the main correlations between different choices to be represented, without requiring the sophistication of full correlation, such as could be offered by a "probit" model.

Estimation procedure

The tree logit model form was chosen as the most general that could be reliably estimated with the commercially available software. Improvements were made, however, to the software being used to increase its capability, operating speed and the size of problems that could be handled.

Model estimation was based entirely on 'revealed preference' data, collected in a home interview survey following a structural design fairly typical of transportation planning. However, advantage was taken of the most recent developments in survey design to improve the quality of the data and to maximise the response rate.

The software used, Hague Consulting Group's ALOGIT package, performs a full-information maximum likelihood estimation of the tree logit model. A limited extent of further non-linearity in coefficients of the "utility" functions of the alternatives is also accepted: models can be specified that contain "size" variables measuring the attractiveness of the alternatives (Daly, 1982). Non-linearity in the measured variables, eg in travel time for walk and cycle modes, is easily accommodated in logit models.

However, the very large model systems defined for this project proved to be too large for simultaneous estimation of the entire system for a single travel purpose. The models were therefore segmented a priori and the segments estimated as tree logit models. Subsequent improvements in computer hardware and the ALOGIT estimation software would allow this decision to undertake a priori segmentation to be reconsidered in a future study, although the complexity of the system would remain a difficulty.

Computer software and hardware issues played an important part in the model estimation. The key packages used were ALOGIT (mentioned above) and EMME/2, which was used for the network analysis to support estimation. Both of these packages were available both on Vax mini-computer systems and industry-standard microcomputers. However, as the project continued, the improvement in performance of microcomputers together with their greater convenience of use, led to their increased use in the later parts of the project.

MODELLING RESULTS

Space does not allow presentation of the detailed model estimation results. Detailed reports are available in Swedish (Widlert, 1992; Algers, 1992). However, to give an idea of the models, a general description of the work model and the shopping models will be given below. More detailed modelling results for the work model are also given in Algers et al. (1990) and for shopping trips in Algers et al. (1992). The complete model system recognises ten travel purposes, although some models are used for more than one of these.

Work travel

Overview

The complete work trip part of the model system is shown in Figure 1. The whole structure is too large to estimate in one step. Therefore, the structure has been split into substructures, indicated by the dotted lines. Each of these substructures has been estimated separately.

The Figure shows the choices for a household with two working members. If a household only has one working member, the complexity reduces considerably. If the household has more than two working members, two "main" workers are identified. The other working members of the household are then treated individually (as special one-person households). The two main workers are denoted A and B, the coding procedures are such that A is usually a man and B a woman.

At the top of the structure is the car ownership model. The next model in the structure is a destination model for the simultaneous choice of workplace (destinations denoted D1 to Dn) for the two main workers in the household. One variable in the destination model is a logsum from the "lower" models in the structure, measuring the accessibility of each destination.

The middle substructure consists of models for trip frequency, car allocation and mode choice. These three models are estimated simultaneously. A logsum from this substructure is then calculated and passed "up" to the final substructure, car ownership and destination choice, which are estimated simultaneously. On the mode choice level, the alternatives are car as driver, car as passenger, public transport, walk and bicycle. Of course, the car driver alternative is available only if the household has a car and if the person has a driving licence.

On the car allocation level, the alternatives depend on the number of working people in the household. If only A goes to work, he has the alternatives of using the car (A) (if he has a licence) or not using the car (0) in the car allocation step. If he does not take the car he can choose between going as car passenger (in another household's car, or with a non-working driver from his own household), going by public transport, walking or cycling. If only B goes to work she has a corresponding choice set.

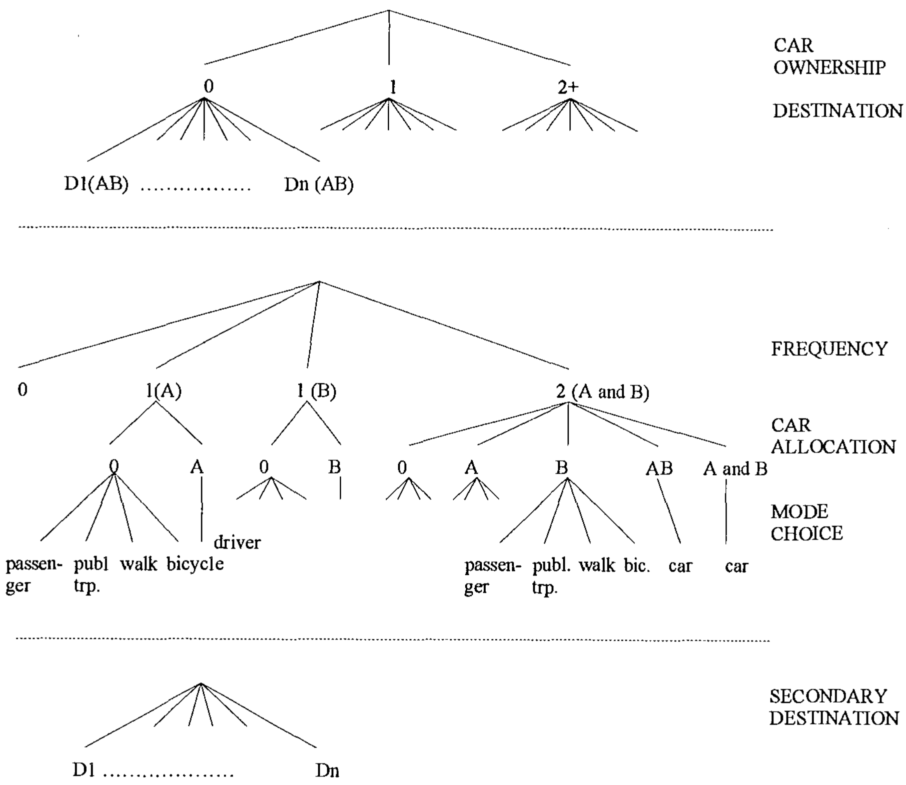

Figure 1 Structure of work trip model

If both A and B go to work, they have 5 alternatives in the car allocation step. One alternative is that nobody uses the car. Two more alternatives are that either A or B takes the car. Finally, both A and B could go in the same car, or in separate cars each (given that the household has more than one car).

In the frequency model, the alternatives are that the household makes no trip (0), that person A makes a trip to work (1(A)), that person B makes a trip (1(B)), or that both persons make a trip that day (2).

The "lower" model in the work trip structure is a model for choice of secondary destination during work trips. Secondary destinations are for example shops etc. visited on the way to or from work. This model must be estimated first in order to calculate the logsums to be passed "up" to the next level.

The estimation results for the work model are briefly described below. The models are described in the order of estimation (ie from the bottom up in the structure above).

Secondary destination

The choice of secondary destinations is modelled as two explicit choices: the choice of whether to chain a second trip purpose or not; and if so, to what destination. In this case, the location of home and work is assumed given, as well as the mode for the "primary" work trip. Since the mode is given, separate secondary destination models are defined for each mode.

The modes considered are car and public transport. Slow modes are not considered, because of the fact that they mostly concern short trips within one zone. The mode used to the secondary destination is assumed to be the same as for the primary tour.

The variables used in the model are attraction variables, network variables, socio-economic variables and constants. In summary, the models allow us to model the impacts of transport systems on secondary destination choices in a reasonable way.

Mode choice, car allocation and travel frequency

At the mode choice level we find different time and cost variables with higher valuations for out-of-vehicle components. As expected, people who sometimes use their car during work have a higher probability of using the car on all days. A car competition variable reflects competition with non-working members of the household (competition with the working members is explicitly modelled at the allocation level). A dummy variable captures the higher probability for travelling as car passenger for workers belonging to a car owning household, reflecting the possibility of travelling as passenger with a non-working member of the household (car as passenger with a working member is defined as shared ride). When it is freezing weather, the probability of cycling decreases substantially.

A logsum variable from the secondary destination model is significantly different from zero, indicating that the accessibility to different destinations on the way to and from work with different modes affects the choice of main mode, as was hypothesised when specifying the structure.

On the car allocation level, sex variables show that women—ceteris paribus—have a lower probability of getting access to the car in households with two working members. This might be interpreted as different bargaining positions because of traditional roles for women and men. Dummy variables indicate that younger women and women with higher education seem to be more equal to the men when "negotiating" for the car. A logsum variable measures how the accessibility affects the car allocation. The parameter shows that the accessibility gained by using the car is an important element when the household decides about the car use.

In the frequency model, weekday parameters reflect the lower work trip rate on Saturdays and Sundays. The part-time dummies show that people who work part-time often work fewer days (not only a shorter time each day). A dummy for households with children (age 7 and under) and two workers shows that such households have a higher probability of staying at home (normally because a child is sick). Dummies for the alternatives with one trip show the same effect—when there are small children in the household, there is a higher probability that one (working) member stays at home. The logsum variable from the allocation model is small and not significantly different from zero. Accessibility has not been found significantly to affect the number of work trips per day for working households. It might, however, influence the choice of part-time employment versus full time employment, which is not modelled.

Destination and car ownership choice

As mentioned above, the destination model deals with the household's choice of combinations of workplaces for both working members in the household (if there are two). In the destination model, there is a logsum variable from the lower levels, measuring the accessibility of different destinations, given the possible modes for the household. In this way, it is possible to take account of the effects on the destination choice of the benefits of the two people working so close together that it is possible for them to travel together in one car. There are also variables that take account of the fact that some parts of the Stockholm region are in reality more or less self-contained working areas. Different distance related variables capture information effects.

In the car ownership models there are income variables showing a stronger income effect on the second car than on the first, and different variables connected to the size of the household—also showing a stronger effect on the second car. Parking costs in the living area are shown to affect significantly the car ownership levels. A logsum variable that measures the increased accessibility to all alternative destinations when the household has one or two cars also has a strong effect on car ownership.

Shopping tours

Overview

The structure of the shopping trip part of the model system is shown in Figure 2.

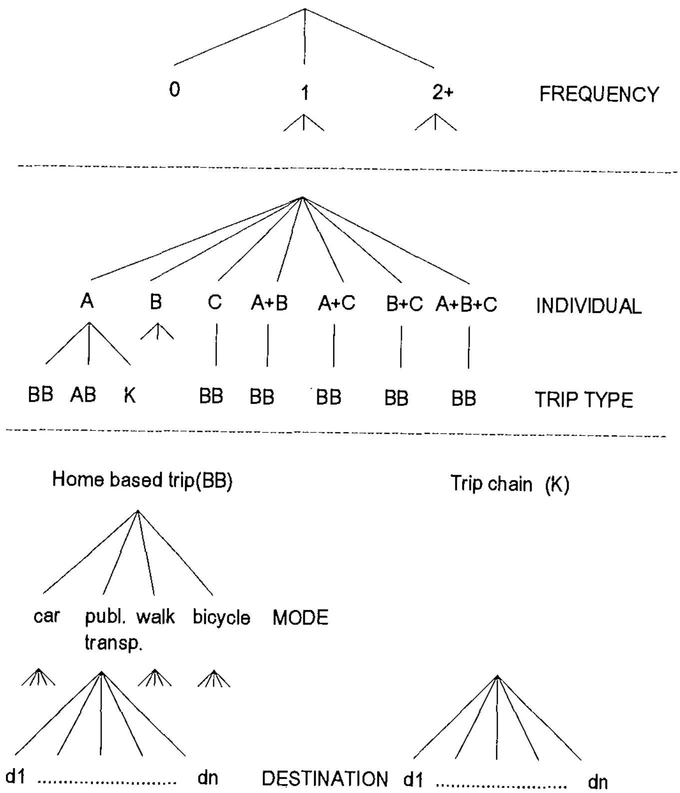

Figure 2 Structure of shopping trip model

At the top of the structure is the frequency model, modelling the number of trips per household. The period for which the frequency is defined, is a day. The alternatives are zero, one, two or more trips, giving an adequate range of altematives.

At the next two levels below, the allocation of the household trips to individuals and trip type is modelled, ie the allocation of a household trip to one or more household members, and also to one of the following trip types: home based tour, work based tour or a work trip detour. The household is divided into an A-person (a worker, generally a man), a B-person (a worker, generally a woman) and unspecified C-persons (the other household members of 12 years and above). Combinations of these three persons or person types yield 7 alternatives to which a household shopping trip can be allocated: A, B, C, AB, AC, BC and ABC. Of course for some households some of these possibilities may not be available.

Below those levels, mode and destination choice are modelled for home-based tours, and destination only for work based and secondary destination trips. The decision unit in these models is the combination of individuals that make the trip together. It may thus be only one person, or the whole family travelling together. The variables are calculated to reflect the number of people in the party, so that all variables are on a per person basis.

The mode choice alternatives for home-based tours are car, public transport, walk and bicycle. The car mode was allowed only if someone in the shopping party had a licence and the household had a car. The destination alternatives are the 850 zones that make up the zonal subdivision of the Stockholm County.

Shopping trips are not very homogeneous. Some trips concern daily needs that are bought in small quantities. Other trips may concern daily needs but in large quantities, and yet other trips may concern durables of differing value (such as clothing and TV sets). The more homogeneous the good in question, the smaller the chance that a more distant destination will give an advantage (or, the smaller the variance in the utility of the destination). This means, that the scale of the model may be different according to type of good.

This is reflected in the model system by separate models for minor daily shopping (defined as daily shopping with a short activity duration) and for other shopping (daily shopping with a longer duration and other types of shopping). The difference between these two groups is reflected in the mean trip distance, which is 3 and 13 km respectively (round trip). These models are referred to as MD (minor daily shopping) and OS (other shopping) models. The division is maintained throughout the model structure.

Mode and destination model for home based trips

The variables for mode choice include cost, in-vehicle time, out of vehicle time components for public transport (walk time and waiting- and transfer time), and distance for the walk and bicycle modes. In the MD model, the trip type components for public transport could not be modelled separately (due to the small number of public transport trips in the data), and therefore the parameters for these variables were restricted to be twice the value of the in-vehicle time parameter.

The destination variables include attraction variables (number of employees in some branches), and dummy variables for supermarkets, regional centres and city areas. The parameters of most of these variables are significantly different from zero. The destination and mode choice levels are connected by a logsum variable.

It should also be noted, that although the implicit value of time is roughly equal in the two models (24 and 20 Swedish crowns per hour, respectively), the time, cost and distance parameters in the MD model are approximately twice the size of the same parameters in the OS model. This is most likely a reflection of the differences in the variance of the utility of the destination as mentioned above.

These models were also used to calculate the logsum variables to the next level in the model structure—the trip type model.

Choice of destination for work based and secondary destination trips

There is not an explicit destination choice model for work based trips. These are normally short walk trips that are of limited interest per se. To calculate a logsum for the next choice level (trip type), a size variable was created for the zones close to and including the work place. The logsum then expresses the accessibility to shops from the workplace (although not necessarily on the same scale as the logsum from the home-based model).

The destination for shopping trips that are carried out in the course of the trip from work to home (or reverse, which is not that common), is modelled by means of a secondary destination model described in Algers, Daly and Widlert (1990). This model was also used to calculate the logsum (for car and public transport, respectively) for the trip type level, expressing the accessibility to shops in the course of the work trip context (on another scale). For persons not choosing car or public transport for their work journey, a logsum measure similar to that for work based travel was calculated.

Choice of trip type and individual(s)

The main variables in this model are work time and logsums from the trip type models. We might expect that longer working time will make the time constraint more binding for home based trips and trip chains than for work based trips. Thus, negative working time parameters would be expected for the first two categories and a positive parameter for the third category. However, longer working time will also increase the probability of shopping for consumption at work. This should increase the working time parameter for work based trips.

The results support this, although not all work time variables turned out to be significantly different from zero (and are therefore not included in the models). The results imply, that with increased work time for both man and wife, the probability that the wife will carry out the shopping increases.

A new finding, however, seems to be that the accessibility of different trip types has an influence on the choice of trip type, and that the accessibility of different combinations of the household members has an influence on the allocation of the shopping trip in the household. At the trip type choice level, the logsum parameters from the home based trip type and the work based trip type is significantly different from zero in both models. Also, the logsum parameters at the level of choice of individuals are significantly different from zero (although the logsum parameter in the OS model is restricted to one, since it otherwise would be—marginally—larger than one). Thus, it seems that the estimated model has proved that there is an allocation process in the household, and that accessibility (and thus transportation) has an important role in this process.

The fact that the logsum (or accessibility) from the secondary destination model did not turn out to be significant can, of course, be caused by the fact that it does not have an impact on trip type choice, or that the secondary destination model was not precise enough (since it was modelled for a mixture of trip purposes, although some variables were purpose specific). It should, however, also be noted that this accessibility increases with trip length, as does trip time. Therefore, increased accessibility from the trip chain between work and home is probably correlated with the time available for shopping.

At this point, the issue of shop opening hours should be addressed. As indicated earlier, the opening hours of shops might be an important restriction on the choice set, and therefore on shopping trip behaviour. However, this was not found to be the case. Such restrictions were tested at the mode and destination choice levels as well as at the trip type and individual choice levels (giving different logsums). In both cases, the differences were found to be very marginal (given the difficulties of defining restrictions of this kind). Thus, it seems as if working hours form more important restriction on shopping trip behaviour than do shop opening hours, that can be expected to be adjusted to meet demand for commercial reasons. This finding, however, may well be specific to Stockholm.

From the trip type and individual(s) choice substructure, a logsum variable is calculated, to be used at the next level in the choice structure. This logsum variable can be said to express the accessibility of the household to shops—over possible destinations, over possible modes of travel, over possible trip types and over possible household combinations.

Choice of frequency

The variables in this model are socio-economic variables and the logsum variable from all the choice levels below. The role of income appears to be complicated, in that income over a certain level does not seem to increase demand for shopping trips with short duration, whereas income increases the demand for other shopping trips on Fridays. This would be consistent with a "shopping strategy" distribution meaning that households with higher income to a larger extent choose to make fewer trips (with larger quantities and concentrated towards Friday, the traditional day for weekly shopping), and that households with lower income are more inclined to shop more frequently.

The logsum variable makes the whole structure of the shopping trip model integrated. Thus, changes in the transportation system will influence all choice levels in the model.

Other trip purposes

The models for the other purposes are similar or simpler in structure. For business trips, trip frequency choice, choice of trip chain, choice of mode and choice of destination are included in the logit tree structure. For school trips, only two levels are included: mode choice and destination choice. Social trips have different structures for home based and chained trips. For home based social trips, frequency choice, mode choice and destination choice are included in the tree. For chained social trips, frequency choice and destination choice are included (mode is conditioned on the mode of the work trip). For the other trip purposes (four categories of personal business and recreation trips), the structure is the same as for shopping trips.

Overall modelling results

The results show that it has been possible to take into account a number of modelling extensions, that have been proposed over previous years (at International Travel Behaviour Conferences and elsewhere) to improve the modelling of travel behaviour. These are mainly the incorporation of interactions within the household, integration of decisions concerning trip chaining and joint choices by separate individuals, and the treatment of constraints on travel behaviour.

The parts of SIMS that can be compared with previous Swedish models agree well (weights for components, etc.). The approach with household models has worked well, and it has proved possible to model explicitly a number of additional household interactions. It has also been possible to obtain good statistical quality in the estimates of the logsum parameters that connect different substructures.

APPLICATION PROCEDURES

In a large and complex model system like the Stockholm model, application procedures need careful thought to ensure that the policy issues of interest can be investigated quickly and usefully. For the Stockholm model, three types of output are being considered, each with specific advantages for particular types of policy analysis: these are summary results, network assignments and screen presentations. First, however, attention is given to the basic structure of the forecasting system.

Forecasting framework

A range of application procedures may be used for the application of disaggregate models, the choice of the most appropriate method depending on the policy issues to be analysed and the structure of the models to be applied. Additionally, software issues can be vital in ensuring correct and efficient implementation of complicated models.

Level of detail of forecasting

An important component of the policy to be investigated with these models concerns the evaluation of infrastructure investment. Infrastructure can be evaluated effectively when the likely flows on the new links are known, ie implying the need to make assignments of traffic. Both highway and public transport infrastructure is under consideration and both types of assignment are therefore needed.

The assignment package used for most purposes in Stockholm is EMME/2. Like other assignment packages, EMME/2 requires that demand be presented in the form of zonal matrices. Thus it is necessary for the travel demand forecasting system to be able to produce matrices on a zonal basis. A system of about 850 zones has been developed for the Stockholm agglomeration for other purposes and seems suitable also in this context. A high level of spatial detail is necessary for accurate public transport assignment.

It is not necessary to meet the needs of accuracy in assignment that non-zero forecasts should be made for every cell in an 850*850 matrix. Previous experience has shown that some degree of sampling is acceptable among the cells of the matrix. Simplest is to sample 100% of the origins, but for each origin to sample a fraction of the destinations, say 10-30%. By choosing the most important (ie largest flow) destinations, which are typically nearer the origin and city centre destinations, a large fraction of the flow (90% or more) can be covered and by expansion the entire flow can be estimated with high reliability in 10-30% of the computer time that would be needed to evaluate the full matrix. Currently a stratified sample of 200 zones is used.

The need for the emphasis on spatial detail implied by assignment at the level of 850 zones (even after destination sampling) means that the role of socio-economic detail in the forecasting system needs to be considered carefully. It is not at present feasible to evaluate the model for a large sample of households, ie making a full "sample enumeration" forecast, in each zone when the zonal system is so large. The best procedure seems to be to analyse the models carefully to select the most important socio-economic distinctions that need to be retained for accuracy. Other socio-economic distinctions must be approximated.

This approach leads to a system of segmentation in which the key socio-economic distinctions are preserved. The segmentation differs by purpose: for example, for the education model students attending different types of school are processed separately (11 segments are represented in the school model), while for the journey to work model these distinctions are of course not relevant, while others are (84 segments are used).

Detailed structure of the models

The model system as it is applied is treated separately by travel purpose. That is, while there are some limited dependencies (in particular, travel for other purposes depends on decisions made for travel to work) the primary structure that governs the model implementation is that of travel purpose. Since other purposes depend on the work purpose, the work model must be run first.

Further, the model systems have been based, as indicated above, on behaviour observed in a home interview survey and the models have been estimated to represent travel generated by households. Thus it is natural to find that for each travel purpose the models are organised by the zone of residence. Each zone is processed separately in turn. The further structure of the models varies by purpose. The forecasting software therefore displays differing structure at lower levels: destination and mode loops are entered as appropriate as are the purpose-specific structures such as car allocation.

An important aspect of the software structure is the treatment of the various segments in the models, which vary by travel purpose. However, in all cases there is a large degree of overlap between the terms included in the utility functions for differing segments. By appropriate structuring of the program, evaluations are made only of those parts of the utility functions that are different for specific segments. This structuring has the consequence that the loops for different segments are found at a low level in the structure of the implementation programs. The effect of this careful structuring of the programs is that the large number of segments (up to 420) does not have as large an impact on the run time as might be expected.

At the implementation of the system some simplifications have been made in order to reduce computation time. The destination choice model for work trips, which is modelled as a combined choice by the members of a two worker household, is for instance implemented under the assumption that the choices are made independently by the two workers. Theoretically, the choice of workplace of one person may be influenced by the possibility of travelling to work together with the other person, but the inclusion of this link would require an increase in computation that is out of proportion to the marginal improvement in the quality of the model that it would give. Another simplification is in the calculation of the accessibility measures for chained business trips. Daly and Lindvelt, (1995) have shown that there is little loss of accuracy if these measures are replaced by the corresponding measures from the work based business trip, which are much quicker to calculate.

A further modification of the originally estimated model system was to implement the mode and destination model (with some restrictions such as trip length) also for work based trips, for which no explicit model had been estimated (only the attraction of the neighbouring zones was used). This simple change increases the applicability of the model for evaluating policies for central areas.

The current implementation of SIMS requires a good 7 hours on a 60 Mhz Pentium PC (not including social trips). However, some potential to reduce the runtime still exists, apart from commercial hardware and software improvements and the possibility for parallel processing of some parts of the model. This is because the model for service- and recreation trips contains some variables to reflect differences between subpurposes, which are now treated as completely different models.

Calibration was done for each trip purpose against the survey-data from 1986/87 as well as census data (work trips) with respect to mode split, frequency and destination choice (at an aggregate level of 11 zones). As a first step, the model was implemented to be used for the morning peak period (6-9). The calibration result is shown in Figure 3. The average trip lengths by purpose in the morning peak are shown in Table 1. These results give little cause for concern about the correct functioning of the model, at least at this level of detail.

Table 1 Average trip length by trip purpose, SIMS and Stockholm travel survey, morning peak

Trip purpose:	SIMS (km)	Survey (km)
Work	21.7	22.1
School	11.9	12.3
Business	16.1	20.2
Shopping	8.2	9.2
Service/recreation	11.6	12.4

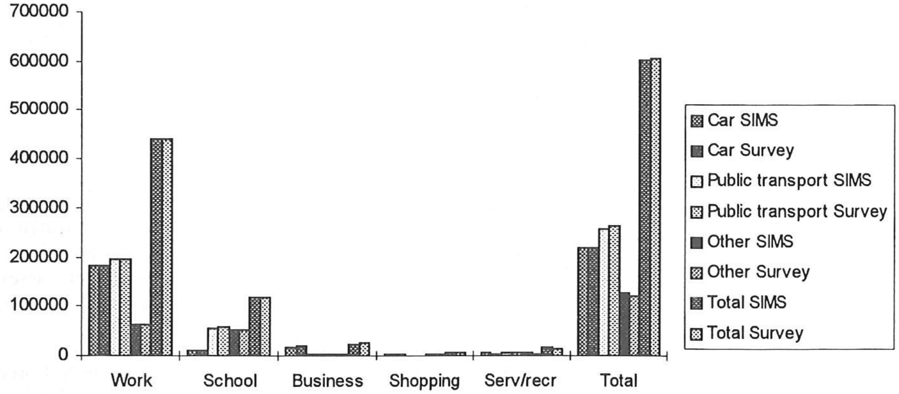

Figure 3 Number of trips in the morning peak 6-9

To make routine work with the model system more convenient, an interface has been programmed (in Visual Basic), which makes it possible to choose input, as for instance population, level-of-service files, but also to choose form of output (ie matrices for different applications). It is also possible to directly choose among output matrices from other systems such as EMME/2 or VIPS. The interface also allows important variables to be changed in a more generalised way, like decreasing all travel times by public transport by 5 %.

Use of forecast results

Results from a forecasting system of the type described here are typically used in detail for network assignment and in summary to report the main impacts of policy. A structure adopted in some other forecasting systems is to use a system for generating summary results separate from the main forecasting system. While this organisation can have advantages, in particular if a very fast summary system can be set up, the need to approximate and therefore to generate results that are different in detail from the main results often causes confusion.

For the Stockholm Model, summary results are drawn from the main forecasting system. The summary results are output from the forecasting system in the form of a file containing the information needed with respect to a number of dimensions that are of interest for summary reporting. Numbers of trips, kilometres travelled, etc. are available for the various travel purposes and modes, and can also be broken down by origin and destination and by various specifications of traveller type. While these dimensions are too numerous to use all of them simultaneously, by the use of appropriate software selections, aggregations and permutations can be presented in many different ways suitable to the analysis of different policy issues.

An important part of the evaluation of alternative policy packages is the presentation of the results to people who are less familiar with the analytical approach and the model structure. Therefore, display capabilities have been developed which allow attractive and flexible presentation of the results in many ways. These display capabilities are integrated with the tabulation facilities described above and share many common features. Assignments to both highway and public transport networks are performed in Stockholm using the separate network analysis software. The demand forecasting system therefore produces files that can be directly input into such software, which offer their own display features to present the results of assignments.

APPLICATION

The Stockholm Model System has so far been implemented at Stockholm Transport, where most of the models described above have been in use since the end of 1994. The last trip purpose (social trips) and the models for choice of secondary destinations for chained trips will finally be fully implemented in 1995.

Use of the model system

The model system has been used at Stockholm Transport and is planned to be further used, mainly for three different purposes. One of these is to analyse the development of all traffic in more general terms in Stockholm as a basis for strategic planning. Another main purpose is to analyse specific projects within the public transport system, for instance to make cost/benefit assessments. Thirdly, the system will be used to increase the knowledge of traffic planners of how the traffic system works and the different factors that influence the transport system.

So far the system has been used in a number of projects within Stockholm Transport. Forecasts for all travel in Stockholm County in the next 5-10 years have been made to serve as a background to the Strategic Plan. The objective has been to describe effects on both car and public transport travel from potential changes outside the public transport system as well as effects from planned investment and other changes in the system.

The model has also been used for analysing a light rail project in the north-western suburbs of Stockholm as well as for analysing a new station for the commuter trains in the southern suburbs.

Validation

In an early attempt to evaluate the implemented model system, forecasts have been made with data for 1993. The changes in overall amount of travel seem to correspond rather well with available aggregate data. As shown in Figure 4, the trip length distribution for trips with public transport during the morning peak (6-9) also corresponds well with data obtained from onboard surveys. The greatest discrepancy is for short trips, where the survey data is known to underestimate the number of trips.

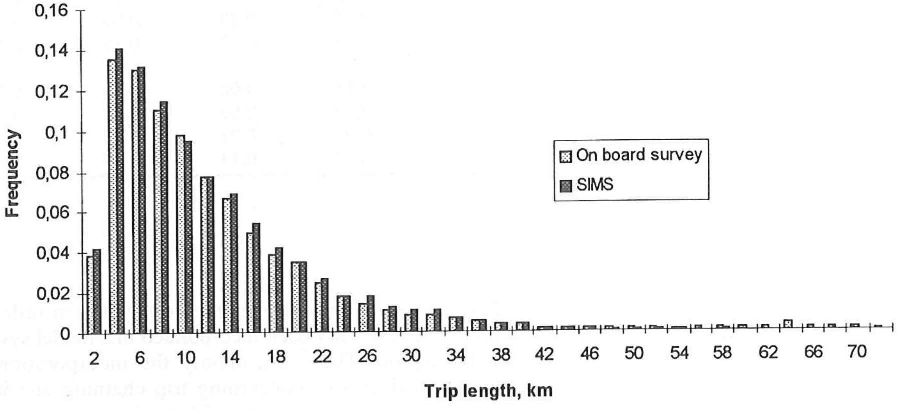

Figure 4 Trip length distribution—forecast and on board survey

Car ownership

The difference between prediction from the car ownership model and official data is however rather larger. The number of cars in Stockholm County has changed dramatically during the last few years. From an index of 100 at the time for the survey (1986/87), car ownership grew to an index of 111 in 1990 and then decreased slightly to an index of 107 in 1993. The model prediction for 1990 corresponds to an index of 109, which fairly well captures what did happen, but the prediction for 1993 corresponds to an index of just over 100.

What happened in Stockholm during these years was that unemployment increased, and the number of employed persons fell back to a level even lower than that of 1986. Car ownership is however a long term decision, and it may well be that the modelled adjustment to a lower level of economic activity will take longer time (also depending on expectations). This type of failure can be expected in a model based purely on cross-sectional data when used for short-term forecasting of a long-term decision. The model does also not takes into account another dynamic effect: the higher car ownership that can be expected by older people over time. A more careful construction of data for 1993 might also have yielded a slightly better correspondence between model predictions and official data.

Elasticities

The model can also be assessed in terms of elasticities. In Table 2, some direct and cross elasticities are presented with respect to the number of trips and for the number of kilometres travelled respectively. The elasticities reflect all day travel (not only the peak).

The elasticities with respect to travelled kilometres are in general larger than with respect to the number of trips. For public transport however, this is not the case for the public transport fare variable. This reflects the public transport fare structure, where monthly passes (which are not differentiated with respect to trip length) are used for most trips.

Table 2 Elasticities with respect to the number of trips and to the number of kilometres

	Elasticities					
	with respect to number of trips			with respect to number of km		
All trip purposes	Car	Public transport	Other	Car	Public transport	Other
Car in-vehicle time	-0.32	0.15	0.08	-0.61	0.19	0.10
Public transport in-vehicle time	0.21	-0.31	0.12	0.36	-0.58	0.15
Car fuel cost	-0.14	0.06	0.04	-0.33	0.09	0.04
Public transport fare	0.11	-0.25	0.14	0.12	-0.25	0.15
Work trips only						
Car in-vehicle time	-0.38	0.22	0.17	-0.62	0.30	0.20
Public transport in-vehicle time	0.35	-0.36	0.30	0.50	-0.58	0.34
Car fuel cost	-0.16	0.09	0.07	-0.31	0.13	0.06
Public transport fare	0.14	-0.17	0.20	0.14	-0.17	0.20

CONCLUSIONS

A number of modelling extensions, that have been proposed over previous years in order to improve the modelling of travel behaviour, have successfully been incorporated in a model system that has been estimated for the Stockholm region. These are mainly the incorporation of interactions within the household, integration of decisions concerning trip chaining and joint choices by separate individuals, and the treatment of constraints on travel behaviour

The model system has further been implemented in a forecasting system, giving forecasts of detailed traffic flows for assignment and summaries of policy effects. The forecast system, which has been implemented with specific regard to computational efficiency because of the increased complexity of the models, runs currently in approximately 7 hours on a 60 Mhz Pentium PC. The more powerful machines now available (eg 120 Mhz Pentium) would reduce that time significantly, although not quite proportionately, while further savings can be made by running the sub-models for different purposes on separate machines (linked, eg by a computer network).

The model system gives a good fit to base-year observation, while its elasticities with respect to simple changes in time and cost variables are entirely plausible. Of course the objective of developing a complex system is to evaluate the complex effects of real-world changes in the transport system and the model system has been used and is being used successfully for evaluations of proposed projects.

The Stockholm model system is believed to represent the state of the art in representing detailed behavioural interactions in a model that is used in applications to a major conurbation.

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