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Issues in Urban Travel Demand Modelling: ICT Implications and Trip Timing Choice

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Abstract

Travel demand forecasting is essential for many decisions, such as infrastructure investments and policy measures. Traditionally travel demand modelling has considered trip frequency, mode, destination and route choice. This thesis considers two other choice dimensions, hypothesised to have implications for travel demand forecasting. The first part investigates how the increased possibilities to overcome space that ICT (information and communication technology) provides, can be integrated in travel demand forecasting models. We find that possibilities of modelling substitution effects are limited, irrespective of data source and modelling approach. Telecommuting explains, however, a very small part of variation in work trip frequency. It is therefore not urgent to include effects from telecommuting in travel demand forecasting. The results indicate that telecommuting is a privilege for certain groups of employees, and we therefore expect that negative attitudes from management, job suitability and lack of equipment are important obstacles. We find also that company benefits can be obtained from telecommuting. No evidences that telecommuting gives rise to urban sprawl is, however, found. Hence, there is ground for promoting telecommuting from a societal, individual and company perspective.

The second part develops a departure time choice model in a mixed logit framework. This model explains how travellers trade-off travel time, travel time variability, monetary and scheduling costs, when choosing departure time. We explicitly account for correlation in unobserved heterogeneity over repeated SP choices, which was fundamental for accurate estimation of the substitution pattern. Temporal constraints at destination are found to mainly restrict late arrival. Constraints at origin mainly restrict early departure. Sensitivity to travel time uncertainty depends on trip type and intended arrival time. Given appropriate input data and a calibrated dynamic assignment model, the model can be applied to forecast peak-spreading effects in congested networks. Combined stated preference (SP) and revealed preference (RP) data is used, which has provided an opportunity to compare observed and stated behaviour. Such analysis has previously not been carried out and indicates that there are systematic differences in RP and SP data.

Keywords: Travel Demand, ICT, Tele-substitution, Revealed Preference, Stated Preference, Mixed Logit, Unobserved Heterogeneity, Travel Time Uncertainty, Schedule Delay

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Contents

List of papers:

(I) Börjesson, M., 2003. A Communication Choice Model.

(II) Börjesson, M., 2003. Telecommuting and work travel demand modelling in Sweden.

(III) Robèrt, M., Börjesson, M., 2006. Company Incentives and Tools for Promoting Telecommuting. *Environment and Behavior*, 38 (4).

(IV) Börjesson, M., 2006. Departure Time Modelling: Applicability and Travel Time Uncertainty.

(V) Börjesson, M., 2006. Joint RP-SP Data in Mixed Logit Analysis of Trip Timing Decisions.

1 Introduction and Scope of the Thesis

Urban regions throughout the world are struggling with fast growing car use and increasing congestion as a consequence. For economical, environmental and social reasons, and considering the large amount of latent demand, new physical infrastructure cannot alone solve these problems. Society is, on the other hand, depending on high accessibility in all segments of the population, particularly to labour markets. This development underscores the need for policy innovations and effective utilization of new technology, which is an important challenge for modern travel behavioural modelling.

This thesis addresses two issues, suggested as potential solutions to these problems. The objective of the first two papers I - II is to investigate if and how the increased possibilities to overcome space that ICT (information and communication technology) provides, can be integrated in existing travel demand forecast models. Another important objective is to investigate how a new data source, the Communication Survey (SIKA 2002), can be used to improve modelling with regard to ICT. KOM is a one-day travel and communication diary survey, carried out on a regular basis, on commission of the Swedish Institute for Transport and Communications Analysis (SIKA).

Paper I, 'A Communication Choice Model', focuses on substitution effects of postal and banking activities. Paper II, 'Telecommuting and work travel demand modelling in Sweden', investigates how telecommuting could be implemented in conventional travel demand models. Specifically, it aims at forecasting future commuting frequency. Paper III, 'Company Incentives and Tools for Promoting Telecommuting', also considers telecommuting, but is more policy oriented. It aims at identifying company incentives for promoting telecommuting to reduce commuting.

The second part of the thesis, paper IV - V, develops a departure time choice model. This model explains how travellers trade off travel time, travel time variability, monetary and scheduling costs, when choosing departure time. This work was part of a larger project called SILVESTER (Simulation of choice between starting times and routes), which aims to develop an application to forecast peak-spreading effects in Stockholm. SILVESTER was largely triggered by the tolls trial in Stockhom, taking place January - July 2006. SP and RP data, used to estimated the demand model, were collected within the SILVESTER project. The demand model presented in this thesis will now be implemented with a calibrated dynamic assignment model within the SILVESTER project. Effects from infrastructure investments and policy measures can then be calculated using this application.

In paper IV, ' Departure Time Modelling: Applicability and Travel Time Uncertainty ', trip timing choice is modelled applying stated preference (SP) data. The paper contains a description of the data collection and model estimation. However, there are certain downsides using stated preference data, as opposed to revealed preference data (RP), describing travellers' actual choices. A common feature of SP data is that response scale is distorted. Paper V, 'Joint RP-SP Data in Mixed Logit Analysis of Trip Timing Decisions', therefore extends the analysis in paper IV by estimating the model using SP and RP data jointly.

2 Research Context

2.1 ICT and Travel

A Backward Glance and Wider Perspectives

The discussion about whether telecommunications substitute passenger transportation has been appearing in transport literature since the 1970s. According to Mokhtarian (1998), the oil crisis was the start of it all, which coincided with the start of the information era. One of the leading ideas was that ICT would create the 'death of distance' in a longer perspective, i.e. that the spatial distance between home, work and stores etc., would play a less important role for activity participation. In this context redefinitions of the concept accessibility have frequently been discussed, see Shen (2000).

This revolutionary perspective was very much an outcome of the fascination of the tremendous technological development. This resulted in a simplified and technology focused way of looking at human activities. Mostly very specific and direct effects from telecommunication services were discussed and analyzed with the prospects that these could be a solution to the transportation problems. The interaction was often categorized as by Mokhtarian and Meenakshisundaram (1999):

Substitution: Telecommunications replace travel.
Generation: Telecommunications stimulate or complement travel, for instance by increasing access to information.
Modification: Telecommunications neither generate nor substitute travel, but change the travel pattern, for instance by time, mode or route.
Neutrality: The use of telecommunications and travel is not influenced by each other.
Indirect (or rebound) effects: The effects described above influence the travel demand and land use in a longer perspective. This may give rise to more spread out residential locations and subsequent effects on local and regional travel patterns and mode choices.

Numerous studies were carried out with the objective to determine which of these effects that were the most dominant. However, very little clearcut results came out of these. Mokhtarian and Meenakshisundaram also note that many of these studies were short-term, and therefore tended to overestimate substitution effect and underestimate the more long-term and complex generation effects. When correlation between amount of transport and telecommunications was found, which was the case in many studies, another problem was to prove a causal relationship.

Several studies in this field were also what Salomon (1998) calls 'armchair studies', which mainly exposed ideas for future research. These were in general very technology focused, and Salomon emphasises that these should not be confused with forecasts. One example is Grübler (1989), who showed how different technologies have emerged and vanished in S-shapes since about 1800, with increasing frequency. He argued that the length of canals, railroads and surface roads, relative to their saturation level, all followed a S-shaped pattern. Grübler then argued that this development pattern is generally applicable when forecasting penetration patterns of modern technology, which is just what Salomon objected to. Mattsson and Höjer and Mattsson (2000) also criticized Grübler for this reason, and further questioned the quality of the data.

It is now clear that ICT impacts on the transportation system reach far beyond and are far more complex than the ones most frequently addressed in literature. The progressive information and communication technology development has changed, and will in the forthcoming decades continue to change, organisation of work and firms (Castells 1996), education, shopping and entrainment industries and land use patterns etc. This reformation occurs in various spheres and levels of society and has thereby a fundamental impact on consumers' behaviour.

On the other hand, analyzing very specific behavioural adaptations like the ones listed above, in response to specific technological innovations has in general not been very successful. These studies have also become substantially fewer. The limitations of them are primarily related to two factors. First, it seems that ICT primarily acts at the travel pattern level, in contrast to the number of trips. Important impacts are presumably such effects as trip chaining, destination choice, departure time choice and meetings arranged at short notice influencing travel planning. In a longer perspective also land use and mode choice may be affected. Deriving causal relationships and calculating the 'net' effect of all these effects is not easily done. Second, there are many factors that simultaneously act on travel patterns, in addition to and jointly with information technology. Such factors are, for instance, economic growth, environmental awareness, work situations and policy measures, etc. In this perspective it is not only difficult but also less meaningful to calculate very specific impacts from information technology.

To exemplify, at first glance the substitution effect from teleconferencing is obvious. On the other hand, this contact (trip or communication) might never been taken if society had been less information and technology dependent and globalized. These kinds of discussions become, however, highly hypothetical and thus not very interesting. Another example is urban sprawl, which have large implications for travel patterns. More flexible work forms (arising from ICT spread) are probably one factor for the increasing urban sprawl. However, also a variety of other factors rule this process, e.g. decreasing travel times and economical growth, and it is very difficulty to assess the effects of these factors isolated from each other.

2.2 Departure Time Choice Modelling and Travel Time Uncertainty

Trip timing choice has received increased interest as a consequence of the time-of-day varying tolls trial in Stockholm (Jan-July 2006). It is expected that driver's preferences for different departure times are an important dimension for policy evaluation in congested regions. In an international perspective there is quite substantial evidence of peak spreading effects (Porter et al. 1995). Traffic flows in peak hour have grown less than those in the overall peak period and peak period traffic volumes have grown less than those in the off-peak. There is also the reverse of peak spreading, peak concentration, resulting from capacity expansion. In Stockholm, this was manifested when the capacity of the most essential motorway was increased, with subsequent increase of peakiness of the traffic flow.

Travel demand modelling and forecasting has traditionally been based upon a four dimensional model, including the frequency, destination, mode and route choice dimensions. The three former choice dimensions are normally unified under the concept demand modelling. Given level-of-service in the traffic system (travel times and cost, etc.), a demand model computes traffic volumes in each origin and destination relation. A route choice model assigns the fixed demand to the road network and calculates travel times and cost, etc. Assignment models have traditionally been based on steady-state equilibrium traffic flows and thus lack the time dimension. Since demand differs largely between on and off peak, traffic is often modelled separately for peak and off peak conditions, and the distribution of demand between peak and off-peak hours is usually fixed. Peak-spreading effects can thus not be studied by this approach.

Few existing large-scale modelling applications in the world deal with the trip timing dimension of travellers' behaviour. Such an application has to integrate a dynamic assignment model with a behavioural model that describes individuals' responses to new travel conditions. Dynamic assignment models differ from steady-state assignment models in the possibility of modelling temporal variations in flows and travel times within a peak period, resulting from queues building up and dissolving.

Most modelling work on departure time choice reformulate the continuous problem to a discrete one, in a random utility framework, following Small (1982). However, the work by Vickrey (1969), who originated much of the conceptually framework of subsequent studies, considered both demand and supply in a continuous and deterministic framework. This, rather theoretical contribution, applied a single link bottleneck model. Focusing mainly on optimal tolling schemes, this work was further developed in a series of articles by Arnott, de Palma and Lindsey (1998). Hyman (1997) and van Vuren et al. (1999) also further developed the work by Vickery, and named this approach "equilibrium scheduling theory". Building on this theory, a software product was developed by Hague Consulting Group (1999), in which the demand model was integrated with the dynamic assignment models CONTRAM, SATURN or TRIPS.

The utility function developed by Vickery and Small is based on trade off between travel time and shift from preferred arrival (or departure) time. As noted by Small and many other authors, the MNL approach is inappropriate for departure time modelling (section 4.1 discusses different model types in more detail). This relates to the obvious ordering of consecutive time intervals in a trip timing model, which induces a specific correlation structure. The MNL model cannot accommodate a correlation structure among the alternatives.

Several studies on departure time choice have therefore used more complex model structures. de Jong et al. (2003) and Hess (2005) estimated error component (mixed) logit models, designed to induce correlation and heteroskedasticity between departure time intervals. Alternatives with departure times closer to each other are assumed to share more unobserved attributes than more distant alternatives. The models also include a mode choice dimension. Estimation thus indicates the relative sensitivity of departure time and mode choice shift, resulting from changes in generalised travel costs. They find that, unless the time shifts considered are very large, the departure time choice is normally more sensitive to travel cost than modal choice.

There is also another class of choice models, GEV models, which can accommodate a flexible correlation structure, but still has closed form choice probabilities. In particular Ordered GEV (OGEV) model should be applied in cases where there is a natural ordering of the alternatives, and is thus well suited for departure time choice. This model was first applied by Small (1987), to an arrival time choice model. Bhat (1998a) jointly modelled departure time and model choice applying a combined OGEV-MNL model.

Trip timing models in the literature have used either SP or RP data. No previous published study has, however, used joint RP and SP data. There are further only few existing studies on trip-choice taking into account that drivers face an uncertain travel time (Noland et al. 1998, Small et al. 2000). These have, as virtually all choice models including travel time variability, used SP data. The exception is Lam and Small (2001), who have used data from a HOT lane [1] project in California, in order to estimate willingness to pay for reduction in travel time variability. This study does not, on the other hand, consider departure time choice.

There are two different approaches in previous studies on travel time uncertainty modelling, the mean-variance approach and the endogenous expected scheduling approach. The former argues that the disutility of travel time variation arises from the difficulty of planning the day because of not knowing exactly when to arrive. This disutility could be captured directly by a separate variable such as the standard deviation of travel time or something equivalent. The latter approach assumes that the cost of travel time uncertainty arise from the risk of arriving at a time different from the desired one and should be represented by the expected value of the scheduling costs variables (equalling the arrival time shift earlier/later from the preferred arrival). The theory of this approach was first proposed by Garver (1968) and Polak (1987). Noland and Small (1995) then further developed the theory, combining it with the work of Small (1982).

An example in Small et al. (2000) illustrates how the expected scheduling delay variables capture the disutility arising from the *risk* of arriving at a time different from the preferred arrival time (PAT). They describe a situation where five possible arrival times (AT) are given, in terms of shift from PAT. These time shifts are -7, -4, -1, 5 and 9, where early arrival is coded as a negative number. Assuming the same probability for these arrival times, the expected scheduling costs are:

$$E(SDE) = E(max[PAT - AT, 0])) = (7 + 4 + 1 + 0 + 0)/5 = 2.4 \quad (1)$$
$$E(SDL) = E(max[AT - PAT, 0])) = (0 + 0 + 0 + 5 + 9)/5 = 2.8 \quad (2)$$

This shows that the averages values of both $E(SDE)$ and $E(SDL)$ are positive, although the arrival time is either late *or* early. This is a consequence of the uncertain travel time and of the fact that expected scheduling costs are non-linear functions of travel time. This explains why the expected scheduling variables capture some of the disutility arising from it.

Since preferred arrival time is required for computing the scheduling cost variables, this approach has mostly been applied in association with trip timing choice modelling. There are relatively few examples of studies comparing

[1] A set of express lanes on an otherwise free and congested road offers high-quality service to people who are willing to pay a time-varying toll.

the mean-variance and the scheduling approach. Also, Bates et al. (2001) provide a link between these approaches by theoretically showing that if the mean travel time is independent on time-of-day (which, on the other hand, in unlikely in a congested network) and no dummy variable for late arrival is included (a discrete arriving late penalty), both approaches are equivalent.

The discussion about of how travel time variability should be represented in choice models, partly originates from the fact that perception and behavioural response to uncertain travel times is still relatively unexplored. Brownstone and Small (2005) review studies on value of time and value of reliability using RP and SP data from two HOT lane projects in southern California. These studies found that standard deviation captures individual's preferences only imperfectly according to the RP data, and that the difference between the 90th and the 50th percentile gave a better model fit (see for instance Lam and Small (2001)). Brownstone and Small suggest that a likely reason for this is that driver's preferences are not symmetric. That is, the chance of a shorter travel time does not influence the driver's preferences as much as the chance of a longer travel time. The difference between the 90th and the 50th percentile is a better indicator of the chance of being considerably delayed, as compared to the standard deviation, which might better reflect what travellers actually care about. Brownstone and Small also suggest that the poor results obtained from using the standard deviation may arise from incorrect measurements.

For an extensive review of travel time uncertainty and departure time choice, see Bates et al. (2001), Noland and Polak (2002) and de Jong et al. (2003).

3 Different Approaches in Travel Demand Modelling

The trend of transportation modelling is obvious. It is becoming increasingly disaggregate in various directions, e.g. in the analysis of individual behavioural responses and its underlying mechanisms, as well as in spatial and temporal resolution. During recent years, much attention has been put on activity-based research in the field of travel demand, as a way to better understand the underlying mechanisms of travel behaviour.

Activity-based approaches are characterized by two key ideas. First, travel is a derived demand, arising from the need or wish to participate in activities within a time and space continuum. This stands in contrast to the conventional model approach, in which the trip itself is the focus. Second, activity-based research emphasises the temporal and spatial possibilities and constraints as well as the context in which individuals or households make their decisions. Travel is assumed to cause disutility in terms of the monetary and time resources it requires. It occurs therefore only when the net utility of an activity performed at a distant location, and the trip that is required to go there, exceeds the utility of the performance of the activity at the original location.

The family of activity-based models includes a set of approaches and methods rather than a model *per se*. These have been developed with a varying degree of detail. Many of the efforts to implement activity-based models have applied microsimulation, which by nature is highly disaggregated in that each agent is modelled individually. (Miller and Salvini 2002)

Since the hypothesised implications of ICT-based services concern the scheduling possibilities and relaxed constraints in time and space, it has often been argued that activity based modelling is better suited for analysis of this process. The work in this thesis starts, however, out from the more conventional methods where the trip is in focus. This is motivated for several reasons. Including implications from ICT in any kind of activity-based model is complicated, and would require a considerable research effort, in terms of time and data resources. It is therefore important to, at the first stage, enlarge knowledge and understanding about how to model behavioural effects from ICT, as much as possible. At this stage, it is less important what model approach that is used. Many of the results from this work apply to the modelling of implications from ICT use per se, and not to a specific model approach. The conventional modelling approach is further very well established and accumulated experiences from data collection, estimation and application are extensive. Extensions of the trip-based approach to more activity-based models are also conceivable.

It has also been argued that the activity based framework is better suited to model trip timing choice, since this is closely related to activity scheduling. Some activity-based models also operate in a time-space continuum. In such models, it is feasible to model trip timing choice as a continuous choice and which reduces aggregation errors. The more conventional, trip based, modelling approach is, however, motivated for the same reasons as discussed above. By developing activity and trip based applications parallel, sound comparisons of their performance should be carried out.

4 Methods and Data

4.1 Methods

Discrete choice methods are used in all papers in this thesis. The first two papers apply the multinomial logit model (MNL). This widely used model relies on the assumption that the error terms of all alternatives are independent and identically Gumbel distributed. From this condition, the irrelevance of independent alternatives (IIA) property follows. This property implies that the cross-elasticity is constant, i.e. that if an attribute in the utility function of one alternative changes, the choice probabilities of all other alternatives change by the same percentage. The MNL model also maintains the assumptions of response homogeneity. All individuals are hence assumed to be equally sensitive to the attributes included in the utility function. (Ben-Akiva and Lerman 1985)

However, there are also more general forms of discrete choice models that relax these assumptions to various degrees. The most general of these is the mixed logit model (Train 2003). The utility functions may include several error components. The utility function of each alternative includes one independent and identically distributed error term, as in the MNL model. Other error components can be specified so as to achieve a desirable variance-covariance structure of the model. The modeller specifies the distributions of these. Several names are used for this model, depending on what property that is emphasized. 'Mixed logit' is often used for its generality. It refers to the fact that it is a mixture of logit models with a specified mixing distribution, i.e. the distribution of the additional error components (Revelt and Train 1998). The name 'Probit with a logit kernel' was used by Ben-Akiva and Bolduc (1996). 'Probit' indicates that the mixing distribution in this model is normal.

Other frequently used terms are 'random taste logit' or 'error component logit'. The former name indicates that this model can accommodate response heterogeneity. The latter refers to the fact that the model allows specification of an arbitrary error-component structure. The difference between the 'random taste logit' and the 'error component logit' is, however, entirely a matter of interpretation (Train 2003). The substitution pattern of this model can be very flexible and determined empirically. The cross-elasticity of two alternatives is larger the smaller the standard deviation of the utility difference is between them. That is, the cross-elasticity of the choice between two alternatives is larger the more common unobserved attributes these alternatives share, relative to other alternatives.

In paper III, IV and V the mixed logit framework is applied in order to relax the assumption of response homogeneity. In the models of the latter two papers, assuming response heterogeneity also gives rise to a favourable error-components structure.

In paper III, the normal distribution is applied to the cost parameter. This distribution is by far the most common mixing distribution, because it is easy to implement and works well technically. The limited number of distributions available in exiting software packages is another reason for wide use of the normal distribution. However, more attention has recently been paid to the fact that the normal distribution is inappropriate in many applications, due to the fact that it is unbounded on both sides and symmetrical (Hess 2005). It is typically unsuitable for travel cost parameters, because we know *a priori* that individuals do not have a positive valuation of travel cost. In paper III, the parameter value for the cost attribute is actually negative for a non-negligible part of the population. Now, in this case it is still possible that some individuals would be willing to accept a salary reduction in order to receive a flexible office. Since the normal distribution is used this conclusion can, however, not be inferred from the data.

To avoid problems with wrong-signed random parameters we have applied the bounded and non-symmetrical $Johnson's\ S_B$ distribution to estimate scheduling and monetary sensitivity in papers IV and V. $Johnson's\ S_B$ distribution is highly flexible and a nonlinear transformation of the normal distribution. It can approximate the normal and log-normal distributions but can also be specified to have a plateau or to be bi-modal shape (Train and Sonnier 2005).

An important advantage of the MNL model is that is has a closed form, i.e. the choice probability can be expressed analytically. In contrast, the (unconditional) choice probability of the mixed logit model cannot be solved analytically. This is instead obtained by integration of the conditional choice probability, over all possible values of the random parameters. The dimension of this integral equals the number of random parameters or error components in the model. For estimation the simulated maximum likelihood approach is most widely used. The simulated maximum log-likelihood function is developed from the simulated choice probabilities.

The downside of the mixed logit model is that the estimation times are relatively long. An alternative to the mixed logit is the 'Probit' model. This model also requires approximation of a multi-dimensional integral of each iteration step. The run time is still shorter because the more efficient GHK-estimator (see Train (2003)) can be applied. However, this model is also less general since only normally distributed error components can be used, and has not been used in the work of this thesis.

All simulation-based models involve approximation of multi-dimensional integrals also in the application. These models have therefore rarely been implemented in large-scale applications. As mentioned, there is an alternative class of closed form models, GEV models that also can accommodate flexible correlation structures. McFadden (1978) first derived the GEV-class of models, and five different model structures in this class have so far been developed. For an overview of these see Bhat (2002).

For trip timing choice the Ordered GEV (OGEV) has received much attention because this model should be applied in cases where there is a natural ordering of the alternatives. The disadvantage of GEV models is, however, that they, in contrast to the simulation-based models, cannot accommodate correlation in the unobserved utility (the error term) across different choices. This kind of correlation often arises across choices within the same individual in data sets that contains more than one choice per individual (this often is the case in SP studies). The OGEV model structure was tried in the departure time choice modelling process, but was rejected because of the importance of correlation in the unobserved utility across different choices.

For the estimations, the software program ALOGIT was used in paper I and II and partly in paper III. In paper III the estimation procedure of the mixed logit model was individually programmed in the programming language Ox. In paper IV and V the software program BIOGEME (Bierlaire 2005) was applied.

4.2 Data

In this thesis several data sources have been used, both SP (stated preference) and RP (revealed preference) data. The stated preference method is based on hypothetical choice situations presented to the respondent and is widely used in the marketing field to analyze consumer behaviour (Louviere et al. 2000). Revealed preference data exposes the respondent's actual behaviour in a real situation. SP data and RP data both have advantages and limitations. Combining RP and SP data in discrete choice modelling, have therefore a long tradition (Ben-Akiva and Morikawa 1990). Methodologies to use the two types of data sources simultaneously in model estimations are well established, and the widely used logit (see section 4.1) model has so far been the predominant methodology (Bhat and Castelar 2002). Joint SP-RP estimation is carried out in the final paper in this thesis. However, as discussed more advanced model structures than the MNL model is used to overcome certain limitations of the logit model structure.

The data primarily used in the first part of the thesis (paper I and II) was not collected for the present studies in particular, but is a repeated one-day travel and communication diary survey called the Communication

Survey (KOM). Swedish Institute for Transport and Communications (SIKA) collected KOM on a yearly basis (the collection is now carried out with longer intermissions). The collection was first designed in 1996, and the design is very typical for that time, when there was a very general interest in the explicit link between travel and other modes of communication behaviour. In this data all transmitted contacts are included, and are categorized into mail, e-mail, phone, cell phone, Internet, fax or video and teleconferences. KOM further includes traditional socio-economic and geographic data, but also data concerning access to telecommunications equipment and telecommuting habits. This data was partly for modelling purposes and partly for descriptive purposes. The modelling studies in this thesis are, however, so far the only ones that have been carried out using this data.

The data used in paper III was collected through a SP survey at the telecom company Ericsson in one office district in Sweden. The SP questions were supplemented with questions concerning the respondents' preferences for telecommuting and actual experience with this work form. The employees received the questionnaire trough the company internal mail-system. The aim of this survey was to discover company incentives to promote telecommuting and identify tools that the company can use to promote this work form. The company incentive addressed in the SP survey was the potential savings from reduced rental costs that a company may gain from introducing flexible offices simultaneously with telecommuting.

The survey conducted to obtain data for the estimation of the departure time model (paper IV and V) was also specifically designed within this project. An SP survey, designed to explore the trade off that commuters make between shifts from the preferred departure time, travel cost, travel time and travel time uncertainty, was carried out in the spring 2005.

The population from which the respondents were recruited consisted of car drivers travelling toward the city centre during the extended morning peak period (06.00-10.00). The drivers were first registered by road side number plate registration, and a survey agency then called them the same evening. Information about the observed trip (i.e. purpose, departure time, travel time and preferred departure time) as well as some socioeconomic information (including income) was collected. An SP survey was mailed to them the following day.

The RP data included the same set of respondents. Information concerning actual mean travel times was obtained from the dynamic assignment model, CONTRAM (Leonard et al. 1989), calibrated for a Stockholm network. From this application we obtained travel times for the extended morning peak (6.30 - 9.30 a.m) with 15 minutes interval resolution. Data on day-to-day variation in travel time was collected from traffic cameras, measuring travel times of three different road stretches, all ending in the city centre.

5 Results and Discussion

5.1 Paper I, 'A Communication Choice Model'

This paper investigates several models with different structures, assuming substitution between contact- and travel-based postal and bank activities. The final model shows interesting relationships between socio-economic status and communication and travel demand for post and bank activities. Well-educated people perform more contacts by telephone and Internet than others. Women use the telephone more, while men are more inclined to use the other modes of communication, including travel. Older individuals have lower accessibility to Internet. The age effect for Internet use is, however, rather weak. This is surprising, since younger people in general are more inclined to adopt new technology. It is possible that older people can better afford Internet use.

The result from the communication model estimation indicates some problems with the model specification and model approach, as a means to simultaneously evaluate contact and travel behaviour. Some of the problems that arose were related to limitations of the data. Other problems were related to the model approach. The different kinds of problems are partly connected, since the size and the type of the data sample restricted the model approach to a large extent.

Since information about the actual activities is so limited in the data that was used, only possibilities of modelling substitution at a one-to-one level could be investigated, for a given activity. Other effects (se section 2.1) are even more complex and modelling these requires that it is possible to link trips and contacts concerning the same activity. More complex ICT implications tend also to be more dynamic and therefore long-term. Modelling these would hence require data that is more process oriented and focused on habits, stretching over a longer period.

Scenario-based stated preference (SP) data, or in-dept interviews could be a feasible way of collecting more process or activity oriented data taking attitudes and perception better into account. SP data collection would also be less dependent of the time lag of the behavioural response to new technology. That is, the adoption rate of the services is likely to be higher than in RP data, enabling more sophisticated modelling analysis than in the present analysis. However, a disadvantage is that SP data may cause behavioural overreactions to new technology based on futuristic ideas.

The problems with the model approach is primarily linked to definition of activities. When assuming substitution at a one-to-one level, as in this model, we assume that the goal of the contact is the same as the goal the replaced trip would have had. Still, even if the goal is the same, the actual activities are in such cases not exactly the same. In reality, substitutable activities may be very different. For instance, downloading a movie or playing games via Internet at home may sometimes substitute recreation activities at other places, such as shopping and visiting friends. Even in cases where the goal of the activities is similar, like for postal and bank activities, are the actual activities are different, depending on the mode of communication (physical or non-physical). The broader the activities are defined, the more difficult it is to identify and specify when substitution actually takes place. This means that the observed substitution effect will in general be dependent on the definition of the activities in this kind of analysis.

Many of the ICT based activities did further previously not exist. Hence, ICT implies in most cases that *activities* are substituted, rather than that the mode of communication is substituted. As the technology develops, activities will continuously be substituted. This process is very difficult to forecast, since it is not only driven by technology development. Attitudes and perceptions play also a critical role for new activity adoption.

Now, all transport modelling approaches is dependent on a pre-defined set of activities. The fact that the actual *activities* change as a result of ICT development, implies that the possibilities of modelling substitution effects are limited, *irrespective* of data source and modelling approach.

5.2 Paper II, 'Telecommuting and work travel demand modelling in Sweden'

The most commonly discussed substitution effect is telecommuting. At present, telecommuting explains a very small part of the variation in work trip frequency between different industrial sectors. Only 124 employees out of 7576 actually telecommute full days at home. In this perspective it is not urgent to include the effect of telecommuting in large-scale traffic forecasting.

Only 38 % of the working force works in industrial sectors in which telecommuting is observed at all in KOM and RES (SIKA 2001) (RES is similar to KOM, but includes only trips and no non-physical contacts). These industrial sectors are concerned with computers, finance or media and communication, authorities dealing with issues concerning infrastructure and environment and universities. Employees with high income and self-employed persons have a larger propensity to telecommute. These groups have presumably high freedom in their work situation. The variables explaining the private situation, i.e., children in the household, living with an employed spouse and house type, seem to influence the propensity to telecommute only marginally. Hence, telecommuting seems to be a privilege for certain groups that have a possibility to actually choose. We can therefore expect that a negative attitude from labour management, job suitability and lack of needed equipment explain the low telecommuting frequency to a large extent.

Telecommuting does not seem to be influenced by or influence low accessibility to the labour market. Surprisingly, individuals with low car competition actually have larger propensity to telecommute. This also points to the fact that accessibility to the labour market was not an important factor for adopting telecommuting at the time when the data was collected.

In summary, KOM data is useful to get an overview of the spread of telecommuting. However, the data is too general and broad with respect to the work force and also with respect to the information on facilitators and constraints, in order to allow for deeper forecasting studies. The number of telecommuters in the sample is very small, which makes model estimations uncertain.

5.3 Paper III, 'Company Incentives and Tools for Promoting Telecommuting'

As mentioned in the introduction, this paper is more directly policy oriented and seeks to find ways to increase the amount of telecommuting. Since the findings in paper II indicated that constraints in the work situation and a negative attitude from labour management hinder telecommuting, this paper aims at identifying means for the company to promote telecommuting.

The basic idea is that telecommuting implies that a large proportion of the company's office space is unoccupied, providing a potential to reduce rental cost. However, to utilize this efficiently, flexible offices must be introduced in which the employees do not have their own office, but use any desk in an open office space. Employees' monetary valuation of the present office place, in comparison to a flexible office is therefore tested, in order to estimate the potential rental cost savings. The results indicate that employees are in fact sensitive to the monetary compensation and that company benefits could be obtained from introducing flexible offices. It is further indicated that employees perceive an increase in work efficiency from telecommuting, which is ultimately profitable to the company.

A majority of the employees in the study further want to telecommute more that they actually do. This finding is coherent with the indication that telecommuting is a privilege for certain groups that have a possibility to actually choose, found in paper II. Consequently we believe that it would be possible to increase telecommuting frequency, in this case as in many others, by changing management attitudes and perhaps also sponsor further computer support and equipment to the employees.

In summary, the result suggests that package solutions, where the company allows telecommunication conditionally on the employees' acceptance of flexible offices could prove to be an effective company policy. In reverse, this kind of package solution might reduce the levels of the monetary compensations for introducing a flexible office. Analysis shows that telecommuters actually demand less compensation to accept a flexible office than others. The compensation to telecommuters could also be designed as company financed technological equipment and related services.

As mentioned no evidences that telecommuting should give rise to urban sprawl, was found in paper II. A joint conclusions from paper II and III is thus that there is ground for promoting telecommuting from a societal, individual and company perspective. It is, on the other hand, not likely that telecommuting will be a large factor for the overall work trip frequency. This is, however, depending not only on how telecommuting is promoted but also on other factors, such as transport costs.

5.4 Paper IV, 'Departure Time Modelling: Applicability and Travel Time Uncertainty. '

Paper IV and V develops a departure time and mode which choice model. This model explains how car drivers trade off travel time, travel time variability, monetary and scheduling costs when choosing departure time. Given appropriate input data and a calibrated dynamic assignment model, the model can be applied to calculate benefits from such as infrastructure investments and policy measures.

The model should primarily be used for analyses in relatively short-term perspectives. Typical examples would be evaluation of congestion pricing schemes and infrastructure projects that are realized within a relatively short time. In longer-term perspective, alterations in traffic generation and destination choice are more important dimensions. These are not considered in the model. Mode choice is further only considered partially, by modelling the propensity to switch from driving. It does not, however, take into account that public transport travellers may switch to driving.

Previous studies analysing travel time variability using the expected scheduling approach (see 2.2) have started out from the assumption that travellers intend to arrive at the most preferred arrival time, PAT. Travellers are thus assumed to choose departure time so as to minimize the risk of arriving too late or early relative to PAT. The present study focuses rather on the traveller's decision to shift intended arrival time, in order to achieve better travel conditions. The departure time shifts considered are therefore considerably larger than those considered in previous studies. Since we assume that travellers shift intended arrival time, expected scheduling cost should be computed with respect to the new intended arrival time, and not to PAT.

Now, the intended arrival time is usually not directly observable, which means that the researcher has to make some assumption about it. A reasonable assumption seems, however, to be that it is equal to expected arrival time. For instance, assume that, for a given departure time and traveller, arrival time usually vary between 8.00 a.m. and 8.30 a.m., and expected arrival time is 8.10 a.m. It is then reasonable to assume that the traveller use 8.10 a.m. as a reference. Arrival earlier than 8.10 a.m. is thus perceived as early arrival, and arrival later than 8.10 a.m. as late arrival. This assumption leads to equivalence of the expected scheduling approach and the mean-variance approach, if the travel time distribution has certain properties. The lognormal distribution, given that the standard deviation of the underlying normal distribution is fixed, and the exponential distribution, both have these properties.

In the present paper the model is estimated using SP data collected for this particular purpose. Estimated scheduling disutility, with respect to travel time, is in line with earlier studies. We found significant unobserved heterogeneity in scheduling costs sensitivity, but no observed heterogeneity except between the three population segments. This points to the fact that there are various conditions that determine the drivers scheduling flexibility, in addition to work scheduling and travel purpose. The explanatory variables available in this study could, however, not capture these conditions.

It was also found that temporal constraints are important both at origin and destination, but that they work in different directions. Hence, temporal constraints at origin are primarily restricting early departure and constraints at destination primarily restricting late arrival. If not taking this into account, scheduling costs was considerably underestimated. Specifically, a large proportion of travellers then appear to have a very low valuation scheduling costs. This could easily be interpreted as SP artefacts, caused by respondents not taken their restrictions properly into accounts, whereas it is actually an effect of the less well specified SDL variable.

Sensitivity for travel time uncertainty, or reliability, is normally computed as a ratio between sensitivity for standard deviation and sensitivity to mean travel time and this ratio is often called reliability ratio. This study shows also that reliability ratio is dependent on intended arrival time. If intended arrival time is earlier than PAT, travel time uncertainty is not significant in the two largest segments. Travel time uncertainty also proves to be least costly, as compared to mean travel time, for travellers with flexible schedule. This result was expected since many of these travellers do not have to arrive punctually.

In order to avoid travellers with wrong-signed scheduling cost and cost sensitivity the highly flexible $Johnson's\ S_B$ distribution, bounded in the interval [-1,0] was applied to all random parameters. The parameter estimates proved to be insensitive to the assumption about these bounds. Analysis further showed that the pseudo random draws perform remarkably well in comparison to the Modified Latin Hypercube Sample (MLHS) draws as proposed by Hess et al. (2006), in coherence with their findings.

Taking correlation in the unobserved heterogeneity across the same individual into account proved to be crucial for correct estimation of the distribution of the random parameters. This implies that valuation of scheduling disutility is randomly distributed in the population, but relatively consistent across all SP choices. If neglecting the correlation of the unobserved heterogeneity we thus fail to estimate the substitution pattern correctly and the model even collapses to a nested MNL model. The consequence of this is that we cannot apply the closed-form OGEV model to this data, which would have been faster in the application, since GEV models cannot accommodate correlation in unobserved heterogeneity. However, model implementation proves that the run times of the simulation based mixed logit model are relatively small compared to the run times of the assignment model, and the mixed logit model may thus be used for implementation.

Finally, assuming that departure times presented in the SP choices differ relatively much from PDT, involves a data collection problem. Including travel time uncertainty and departure time shifts jointly as a attributes, will in general imply that the disutility arising from departure time shifting is larger than the disutility arising from travel time uncertainty. The consequence is that it more difficult to produce reasonable trade offs, which increases the risk of getting poor accuracy in the estimates.

5.5 Paper V, 'Joint RP-SP Data in Mixed Logit Analysis of Trip Timing Decisions'

This paper extends the analysis of paper IV, by using joint RP and SP data. It has provided an opportunity to compare observed and stated behaviour, which is very valuable. No other such comparisons on departure time choice have been published. The present comparison indicates that there are systematic differences in RP and SP data. These differences are manifested in a higher response scale in the RP data, and the fact that scheduling disutility does not prove to be constant across RP and SP choices within each individual. These differences seem, however, to be smaller for commuters with fixed schedule. In order to assess the validity of the model, it is important to try to analyse how these differences arise.

67 % of the respondents reported that they actually departed at preferred departure time (PDT) in the RP data, which explains the high response scale in the RP data. This proportion, and the response scale difference, would probably have been smaller if the cost attribute had been included in the RP data, as well as in SP data. It might also have been smaller if we had asked directly about preferred arrival time, instead of departure time, in the interview.

In the RP data we have further aggregation errors, since we have divided the extended morning peak into 15 minutes intervals, which might have affected estimated trade-offs. This would be one reason for the difference in scheduling disutility between RP and SP choices within individuals. The temporal differences in RP and SP choice situations might also be an important factor. In RP data observed behaviour is a result of a long-term adaptation to actual travel conditions. The SP choice is short-term in the sense that only one particular trip is considered. This has probably implied higher temporal flexibility for some travellers and smaller flexibility for others, in the SP choice. If this explanation is valid, SP data is generally less trust worthy than RP data, given that long-term behaviour and preferences are what we wish to analyse and forecast. In this case long-term refers to at least a couple of months, as opposed to one or a few days. For commuters with fixed schedule we expect that short-term and longer term flexibility is more equal. This would explain why the scheduling sensitivity is more constant across RP and SP choices within the same individual in this segment.

It is possible that the problem with different temporal perspectives in the RP and SP choice would have been avoided if we had asked explicitly for the long-term choice. There are, however, two reasons for presenting the choices as concerning only the observed trip. First, a long-term choice relies on the fact that the trip is made on a regular basis. Asking about the long-term choice thus excludes trips that are not made regularly. Second, we tried to make the choice situation as concrete and realistic as possible. We assumed that this would help the respondents to take their restrictions properly into account. Also, ten respondents taking part in a pilot survey were called after returning the questionnaire. We asked if their choices would have been different if we had asked about their longer-term choice and not particularly about the observed trip. All ten respondents answered that their choices would not differ. This was also a reason for our decision about the survey design. It may still be very difficult to decide about a longer-term choice right away, since behavioural adaptations usually take relatively long time.

6 What Have the Findings Brought to Travel Demand Modelling?

- One-day cross-sectional data in general in unsuitable for modelling ICT implications related to travel.

- The fact that the actual *activities* changes as a result of ICT development, implies that the possibilities of modelling substitution effects are limited, *irrespective* of data source and modelling approach.

- Telecommuting explains at present a very small part of the variation in work trip frequency. There is no evidence that telecommuting should give rise to urban sprawl.

- Telecommuting seems to be a privilege for certain groups that have a possibility to actually choose and a majority of the employees at the telecom company Ericsson want to telecommute more that they actually do.

- Employees are in fact sensitive to monetary compensation and company benefits could be obtained from introducing flexible offices in combination with telecommuting.

- A departure time and mode switch choice model is estimated on joint RP and SP data. It explains how car drivers trade off travel time, travel time variability, monetary and scheduling costs when choosing departure time. Given appropriate input data and a calibrated dynamic assignment model, the model can be applied to calculate benefits from such as infrastructure investments and policy measures.

- We assume that intended arrival is equal to expected arrival time. This implies that the expected scheduling approach and the mean-variance approach are equivalent, if the travel time distribution has certain properties.

- Temporal constraints are important both at origin and destination, but constraints at the origin are primarily restricting early departure and constraints at the destination are primarily restricting late arrival. Sensitivity for travel time uncertainty is only significant of if intended arrival time is later than PAT.

- Taking correlation in unobserved heterogeneity across the same individual into account was crucial for correct estimation of the distribution of the random parameters, implying that valuation of scheduling disutility is randomly distributed in the population, but relatively consistent across all SP choices.

- There are systematic differences in RP and SP data, and these are manifested in a larger response scale in the RP data, and the fact that scheduling disutility is not constant across RP and SP choices within each individual. The scale difference is largely due to the fact that 67 % of the respondents reported that they actually departed at preferred departure time. The response differences accros RP and SP choices might be due to the temporal differences in RP and SP choice situations.

7 Future Research

This thesis shows that conventional travel demand models are not suitable for modelling implications from ICT. Activity-based approaches might, at least from some theoretical points of view, be better suited for incorporating ICT related effects, because of the focus on activity scheduling in time and space. However, since definition of activities is crucial and ICT seems to imply that these constantly change, it will be very difficult to include ICT implications in any explicit modelling approach.

Even if it proved to be possible to model implications of ICT in travel demand models, the problem of forecasting still remains. Perceptions and attitudes, which are critical as explanatory variables for future ICT-based service adoption, are much more difficult to forecast, than conventional socio-economic data. The problem is even more severe if we add the difficulty of forecasting what types of telecommunication-based services that will emerge. ICT and travel substitution will presumably also be very dependent on other factors in society, such as travel costs and economical growth.

Considering these issues, in-dept interviews and stated preference-based data, where scenarios are presented to the respondents, are the only possibility left to forecasting ICT service adoption and travel related implication. This method was used in the European Commission 6th framework POET project (de Jong et al. 2006). However, this kind of data collection is dependent on a realistic description of the scenarios. It is further dependent on the fact that respondents actually know how they would respond to new technology, without actually having experience of it from their daily life.

On the other hand, this work shows, in line with other studies, that the expectation and hope that ICT would reduce travel was exaggerated. It is clear that individuals and commercial business in general have not used the opportunities given by telecommunications to reduce physical travel. The POET study also showed that the effects on travel pattern implied by new ICT service are generally small. As discussed in section 2.1, ICT implications are also presumably influencing travel patterns in a very complex manner and are difficult to distinguish from other factors acting on travel patterns. In this perspective, and given the difficulties of modelling the effects, it does not seem very urgent to spend a large research effort to include implications from ICT in large-scale traffic forecasting.

The primary research effort, from a transport perspective, should instead focus on the challenge to make use of new service innovations to meet the goals set up by society. In this perspective, ICT has the potential to reduce negative effects from transportation. The focus should primarily be on technology that offers a possibility to increase the efficiency of the existing infrastructure supply, i.e. ITS (Intelligent Transport Systems). For instance, improved information services in the public transport and carpooling systems would increase the attraction of these, less resource consuming, travel modes.

A long-term objective of SILVESTER (see section 1), is to later integrate the departure time model with the mode choice model of the Swedish national travel forecasting model SAMPERS (Beser and Algers 2001). However, the demand models of SAMPERS are estimated in another choice context, as compared to the departure time choice model. In the former frequency, mode and destination choice are modelled simultaneously whereas the latter assumes fixed frequency and destination choice. Integrating the departure time choice model directly in SAMPERS, would therefore cause inconsistency. The easies way to overcome this problem would be to re-estimate the mode and destination choice model of SAMPERS. The inclusive value from the departure time model would then replace time and cost variables in the car alternative. This is possible since we explicitly have estimated the RP scale of the utility function of the departure time model.

An obstacle when modelling effects of travel time uncertainty, and for the SP design in particular, was the limited knowledge about the distribution of travel times, and drivers' perception about this. Little was further known about travellers' preferences and behavioural response to this attribute.

Perceptions and behavioural response to uncertain travel times is very difficult to analyse from data collection perspective. In the RP situation the problem is that a very large number of observations is needed to get a correct measurement of the travel time variability. Excluding observations in the cleaning processing must therefore be made extremely careful. The obvious risk is otherwise that observations of unusually high travel times, which are the most important ones, are assumed because of expected measurement errors. The problem of measuring variability in the SP design arises from its complexity, and the fact that this attribute in general is difficult to interpret. A key issue for further research is thus how travellers perceive travel time variability and how it influences their preferences.

The present work also indicates differences in SP and RP data concerning trip timing choice. For traffic forecasting it would therefore be very valuable to analyse RP data including the cost attribute. Such data is presently not available, but can be obtained from the tolls trial in Stockholm. Ideally the respondents taking part in the present survey would be asked again about their departure time during this trial. New respondents could also be recruited and asked about their departure time before, during and after the trial. This approach relies, however, on respondent's ability to recollect past behaviour. It also excludes trips that are not made on a regular basis.

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