Mode choice of complex tours: A panel analysis a panel analysis

Author(s):
Cirillo, Cinzia; Axhausen, Kay W.

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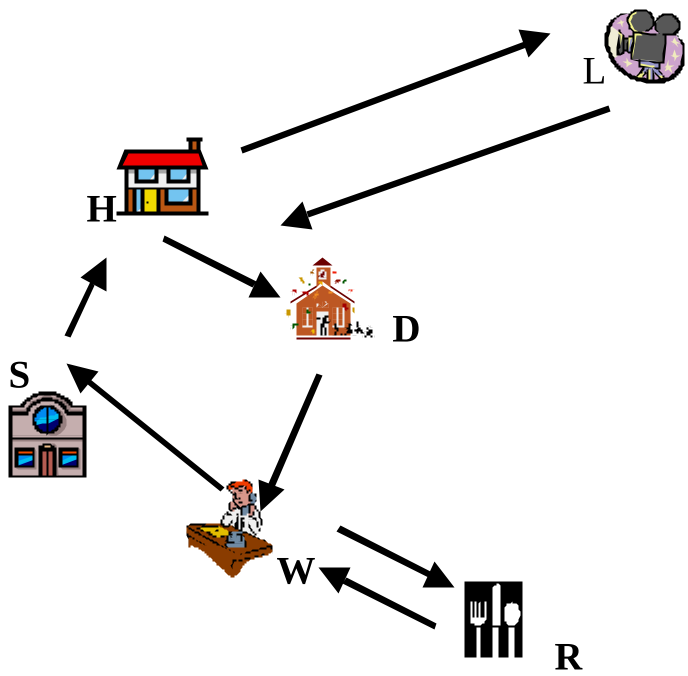

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Mode choice of complex tours: A panel analysis

C Cirillo
KW Axhausen

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Institut für Verkehrsplanung und Transportsysteme
Institute for Transport Planning and Systems

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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Verkehrsmittelwahl in komplexen Touren

C. Cirillo
GRT
FUNDP
Rempart de la Vierge 8
B – 5000 Namur

Telefon: +32-81-724 923
Telefax: +32-81-724 914
ccir@math.fundp.ac.be

KW Axhausen
IVT
ETH Zürich
CH – 8093 Zürich

Telefon: +41-1-633 3943
Telefax: +41-1-633 1057
axhausen@ivt.baug.ethz.ch

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Kurzfassung

Auf der Grundlage der 6-wöchigen Tagebuchbefragung Mobdrive untersucht dieser Aufsatz die Verkehrsmittelwahl auf der Ebene der Tour, d.h. die einzelnen Wege werden als gemeinsame Reise untersucht. Diese Touren werden zu 86.1% mit nur einem Verkehrsmittel durchgeführt, was eine Analyse auf der Ebene des Hauptverkehrsmittels rechtfertigt.

Nach einer Beschreibung der Befragung und des Verhaltens über den Tag stellt der Aufsatz eine Gruppe von multi-nominalen Logit-Modellen vor. Schwerpunkt ist ein mixed logit Modell, dass die Korrelationen der Zufallsterme innerhalb eines Personentages berücksichtigt. Die Modelle enthalten Terme über das allgemeine Verhalten der Person, aber insbesondere auch über das durchschnittliche Zeitbudget ausser Haus und die am Tag schon für Fahrten verwendete Zeit.

Schlagworte

Verkehrsmittelwahl, Touren (Reisen), Logit, Mixed Logit, Mobidrive

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C Cirillo
GRT
FUNDP
B – 5000 Namur

Telephone: +32-81-724 923
Telefax: +32-81-724 914
ccir@math.fundp.ac.be

KW Axhausen
IVT
ETH Zürich
CH – 8093 Zürich

Telephone: +41-1-633 3943
Telefax: +41-1-633 1057
axhausen@ivt.baug.ethz.ch

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Abstract

On the basis of the six-week diary Mobidrive this paper studies mode choice at the level of the tour, i.e. the trips are amalgamated into a journey. In 86.1% of the case these tours involve only one mode. This justifies the focus on the main mode of a tour.

The survey is discussed and a detailed descriptive analysis of the tours and the activity patterns provided. The choice modelling involves both simple multinomial logit models as well as mixed logit formulations accounting for within-group error correlations. The models are specified very richly, including in particular a detailed characterisation of the choice situation, but also of the long-term commitments of the persons and households.

The results indicate: the gains made by properly accounting for within-group correlations; the need to match variables and the time-horizons implied in the model and finally relatively low values of travel time savings in a context where car- and season ticket ownership are considered fixed.

Keywords

Mode choice, tours, logit, mixed logit, value of travel time savings, Mobidrive

Preferred citation style

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1 Constraints in choices

The modelling of mode choice can be undertaken at different levels: in the long-run there is question to which mode the travellers pre-commitment themselves through the purchase of cars, motorcycles or public transport season tickets, in the short run, one can look at the level of the trip or the level of the tour, i.e. a sequence of trips starting and ending at the same place. The sequence of tours between the first departure and the last return to the home forms the daily activity chain.

Traditionally the focus of analysis has been the individual trip, i.e. the movement between two meaningful and substantial activities. For the difficulties in this definition, in particular with respect to the terms "meaningful" and "substantial" see Axhausen (2002). In this type of analysis each trip was seen as an independent event, for which the traveller made a new and separate decision with regards to mode, destination, timing, company etc. As long as symmetrical work tours (home – work – home) were the vast majority of morning travel and as long as they were the main concern of transport planning, this assumption was defensible. This is not the case anymore: the pattern of trip making and therefore of the tours have become more complex; the long afternoon peak with its mixture of work, shopping and leisure travel is now the main concern and the time of maximum demand.

In this paper, we want to address these issues by providing a descriptive analysis of these changed patterns and by analysing mode choice at the tour level. The tour level is relevant, as it has been long known, that travellers maintain their mode during a tour, especially if they use an individual vehicle (car, motorcycle or bicycle). The most variability is observed for tours involving public transport, as the travellers can easily include walking or taxi trips and as they do not have to return to their parked vehicle.

In addition, this paper will look specifically at short-run decision making. The variables included to describe the choice situation will reflect the long-term commitments of the traveller (car and public transport season ticket ownership), as well his/her current habits, as observed during the six-week survey period.

2 Data sources

The Mobidrive data set was collected in the spring and fall 1999 in Karlsruhe and Halle (Germany) (Axhausen, Zimmermann, Schönfelder, Rindsfüser and Haupt, 2002). The aim of the sponsoring project was to understand the variability and rhythms of daily life. It was therefore to decided to collect a six-week diary of a reasonably large sample of respondents. Using the 1970 Uppsala study as an example (Marble, Hanson and Hanson, 1972), but adopting a state-of-the-art approach to the survey protocol and the form design about 160 households with about 360 members were recruited into the study offering a reasonable, but not large incentive payment. This was differentiated by household type (single, couples, families with children: 100, 150 and 200 DM). The sample was recruited to match a one-third share for each of the three household types.

The survey began with a 45-60 min face-to-face interview, which was also used to explain the weekly diary form to the respondents. The form was a derivative of the well-known KONTIV form (see PTV AG, Fell, Schönfelder and Axhausen, 2000) in its layout, but provided enough room for a week's worth of trip making. The respondents returned these forms weekly by a postage-paid envelope. They received the form for the following week each Friday. The field work firms checked the forms on receipt and phoned back, if there were any queries and questions.

Axhausen et al. (2002) document the absence of reporting fatigue with respect to the number of trips reported. Only a few households dropped out after they had started with the survey. The main drop out occurred between the telephone recruitment and the personal interview, or at the personal interview.

The vast majority (95%) of trips reported within the study areas could be geocoded. Based on the geocodes network-based information about the trips were added for both individual and public modes (car: navigation networks; public transport: public transport information system of the local supplier (Karlsruhe only); walking and cycling travel times were estimated using road distances, but using personalized estimates of average speeds). Where necessary, imputations based on the best obtainable speed estimate were added.

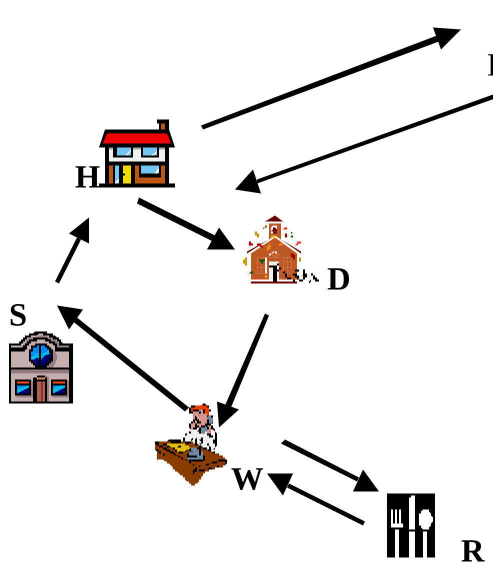
3 Approach to structure the daily activity chain

The daily activity chain can be described by a number of indicators (number of trips, number of tours, total travel times etc.) and by a number of ways of defining patterns in the chain (number of tours, main activity, main mode etc.) (Bhat and Singh, 2000). The main approach employed divides the daily chain into subpatterns, which in turn contain tours. The key reference for the definition of these patterns is the main activity of the day: for workers/students work/education; for non-workers the longest duration out-of-home activity of the day. All daily activity chains or schedules are represented in relation with this pivotal activity and divided into activity subpatterns, themselves resulting in travel patterns. Each tour within a pattern has a main activity defined by duration and purpose. Additionally, within a tour an individual can make further stops to perform secondary activities. The details of the proposed representation for workers and non-workers will be introduced successively (for further details see Cirillo and Toint, 2001).

Workers are individuals who commute on the day considered, in the sense that they go to and return from work. The morning and the evening legs of this commuting pattern are grouped into a single work commute pattern, since the travel mode for both these legs will often be the same; they are referred to as the *morning commute* and *evening commute*. All activities that take place before the morning commute will be referred to as *morning activities*, and the associated displacements grouped into one or more *morning tours*; they constitute the *morning pattern*. Similarly, all activities taking place after the return from work to home (the evening commute) will be referred to as *evening activities* and the associated displacements grouped into one or more *evening tours*; which together constitute the *evening pattern* (Hamed and Mannering, 1993). Additionally, all activities taking place outside the work location after the morning, but before the evening commute will be called *midday activities* and the associated displacements, whose origin and destination are at work, are grouped into one or more *midday tours*, themselves grouped into the *midday pattern*.

The complete daily activity pattern is characterized by a number of different attributes for each component of this representation. These attributes may be classified according to their associated level of representation, that is, whether they are associated with a pattern, a tour, or a trip. See Figure 1 for an example.

Figure 1 Example daily activity chain



Pattern	Tour(s)	Main activity	Other activities
Morning	-	-	-
Commute	H-D-W-S-W	Work	Outbound: Drop-off children; Return: shopping
Midday	W-R-W	Restaurant	-
Evening	H-L-W	Leisure	-

Pattern level attributes include the number and sequence of tours within the pattern, the home stay duration that precedes it, and the *main activity*, which is the activity of maximum duration amongst all activities performed in the pattern[1]. Tour level attributes include travel mode, number and sequence of stops, home stay duration before the tour and work stay duration for work pattern. Stop level attributes include activity type, travel time to stop from previous stop, location of stop, and activity duration.

For non-workers, i.e. those not commuting on the day considered, we replace the concept of work activity by that of *principal activity* of the day, which is defined as the maximum duration out-of-home activity of the day. The remaining activities and displacements can then be

[1] We could define a *main pattern activity* and *a main tour activity* separately, as the activity of maximal duration within the pattern or tour, respectively, but this distinction is not used in the rest of our exposition.

organized in relation to this principal activity in a manner similar to that used for organizing workers' days around their work activities.

- The morning pattern represents the activities and travel undertaken before leaving home to perform the principal activity of the day;
- The *principal activity pattern* represents the activities and travel performed within the tour comprising the principal activity of the day. This principal activity pattern is itself decomposed in a *principal activity access* (the activities and displacements within the principal activity tour but before the principal activity itself), the principal activity proper, and the *principal egress* (the activities and displacements within the principal activity tour but after the principal activity itself). Note that this definition implies that the principal activity pattern always contains a single tour.
- The (afternoon and) evening pattern comprises the activities and travel of individuals after their return home from their principal activity.

Note that the morning and evening patterns of non-workers contain a main activity (not to be confused with the principal activity, which can be viewed as the main activity of the tour containing the principal activity).

4 Descriptive results

This section will provide descriptive results in some detail, as the approach chosen is unusual. Table 1 provides the distribution of the number of tours by patterns and person type. The average number of tours is comparable for workers and non-workers: 1.66 for workers and 1.61 for non-workers.

Looking in detail at the workers' daily pattern one can observe that they do not pursue many out-of-home activities before leaving home for work (only 3.4%), during the midday pattern just 5.4% of them leave the workplace, and that 48.2% of the workers pursue out-of-home activities after they return to home from work. Almost all workers who pursue activities during the morning, midday and evening patterns do so in one or two tours. Non-workers go out in the evening less than workers (21.9%), possibly because they can distribute their activities more freely over the day. The number of tours for non-workers does not differ much from that for workers since around 1.0% of them pursue three or more tours before and after their principal activity pattern

Table 1 Number of tours by activity pattern [%]

Number of tours	Morning pattern	Midday pattern	Evening pattern	Whole day
Workers				
0	96.6	94.6	52.8	-
1	3.1	4.9	38.7	46.9
2	0.3	0.4	7.5	41.6
3 and more	-	0.1	1.0	11.5
Non-workers				
0	74.0		78.1	-
1	20.1		17.6	55.7
2	4.5		3.4	31.6
3 and more	1.2		1.0	12.7

Table 2 reports the distribution of the main activity types by pattern type amongst the Mobidrive population for workers and non-workers, respectively.

For workers, the purpose of the main activity in the morning pattern is daily shopping (38.1%) then personal business (26.5%); other purposes having less than 15%. In the evening 51.0% of the same group has leisure, while 19.2% go shopping and 14.9% go out for personal reasons. For non-workers, leisure (51.0%), shopping (25.3%), personal business (13.3%) represent almost 90% of all the main activities performed by the respondents. The main activity for the morning pattern is again shopping, with a quite low percentage for pick-up/drop off. In the evening non-workers go out for leisure (41.9%), shop (27.6%), and to address personal business (16.1%).

Table 2 Main activity types by activity pattern [%]

Purpose	Morning	To work	Midday	From work	Evening
Workers					
Pick up/drop off	11.6	18.0	1.5	6.3	4.8
Personal business	26.5	34.9	5.3	22.6	14.9
Work related	2.3	13.5	3.2	14.4	1.5
Daily shopping	38.1	20.8	5.0	23.3	19.2
Long-term shopping	6.0	3.8	1.5	7.7	7.7
Leisure	14.9	8.0	5.0	24.8	51.0
Other	0.5	1.0	3.4	1.0	0.8
Return home	-	-	74.3	-	
Non-workers	Before		Principal		After
Pick up/drop off	7.8		3.3		10.6
Personal business	21.0		13.3		16.1
Work related	2.5		4.7		2.2
Daily shopping	37.0		17.5		21.2
Long-term shopping	9.4		7.8		6.4
Leisure	21.7		51.7		41.9
Other	0.7		1.6		1.6
Return home	-		-		-

The analysis of mode choice by patterns and activities performed over the day gives interesting insights into modal usage (Table 3) this matter. The first observation is that workers and non-workers use their car at least once a day with about the same percentages (45 %); non-workers are more likely to be car passengers to perform their main activity than workers. The use of car is constant over the day for the home-based patterns, except that it is higher in the morning for workers. Workers use public transport much more than non-workers, since about 25% go to work by public transport (5.1% by bus, 21.5% by LRT and 1.2% by heavy rail). The use of public transport is smaller in the evening. Non-workers walk more than workers.

A closer look at the data indicates that complex patterns (involving several stops) are performed preferably by car.

Table 3 Main mode shares by activity pattern [%]

Purpose	Morning	To work	Midday	From work	Evening
Workers					
Walk	28.4	15.6	30.4	15.7	26.2
Bicycle	15.3	18.7	33.0	18.9	16.6
Motorcycle	0.5	1.5	-	1.5	1.4
Car driver	48.8	31.4	21.9	31.7	27.8
Car passenger	4.2	5.1	2.9	6.4	17.8
Bus	0.5	4.3	0.3	3.4	0.9
Tram/Light rail	2.3	21.9	7.9	21.0	9.3
Heavy rail	-	1.3	3.5	1.2	-
Other	-	0.1	-	0.1	-
Non-workers	Before		Principal		After
Walk	35.4		23.9		32.1
Bicycle	16.2		9.7		11.3
Motorcycle	0.6		0.7		0.9
Car driver	29.8		33.5		34.9
Car passenger	9.6		20.8		12.8
Bus	0.6		0.9		1.1
Tram/Light rail	7.8		9.7		6.4
Heavy rail	-		0.7		0.5
Other	0.1		-		-

As mentioned before, travellers tend not to change modes during a tour, or a even for a whole day, as can be seen in Table 4. The combinations with a share of 5% cover about 70% of the work day modal chairs, and even higher shares on the weekend days. The pure chains, i.e, travellers using only one mode on any given weekday, make up about 45% of all days in Karlsruhe and about 50% in Halle.

Table 4 Shares of daily modal chains with more then 5% of the total [%]

Daily modal chain	Karlsruhe			Halle		
	Work day	Saturday	Sunday	Work day	Saturday	Sunday
Bicycle only	8.55	5.27	-	6.15	-	-
Car driver only	21.67	20.83	19.37	22.22	22.08	22.14
Car passenger only	-	12.75	17.47	5.76	17.33	19.97
Public transport only	8.46	-	-	10.07	-	-
Walking only	8.46	13.73	22.03	17.20	17.59	23.68
Walk & bicycle	5.93	-	-	-	-	-
Car driver & passenger	-	6.50	-	-	-	-
Car driver & walk	8.44	7.11	5.82	8.35	10.01	8.05
Car passenger & walk	-	6.37	7.22	-	7.70	6.35
Public transport & walk	6.71	-	-	9.22	-	-
Sum	68.23	72.55	71.90	78.97	74.71	80.19

The level of daily chain aggregates the individual tours, which are the focus of this paper. Most tours (86.1%) in the Mobidrive data set are uni-modal in the sense, that use only one type of vehicle, i.e. bus and tram are counted as two modes for the analysis. The share of multi-modal tours increases with the number of trips involved in the tour (6.3% for tours with two trips to 49% for tours with four trips). Among the multi-modal combinations those involving walking predominate, again justifying a main mode focus as implemented later in the choice models (See Table 5).

Table 5 Composition of multi-modal tours [%]

Motorised individual transport	Public transport	Slow modes	Shares of multimodal tours [%]
No	No	No	--
		Yes	8.54
	Yes	No	2.82
		Yes	22.16
Yes	No	No	11.93
		Yes	32.96
	Yes	No	17.64
		Yes	3.95
Involving other modes			0.42

Motorised individual transport	Car driver, car passenger, motorcycle
Public transport	Bus, tram, rail
Slow modes	Walking, cycling

A tour involving two modes within a major category is counted as multimodal

Table 6 shows the average distance from home to the main activity location, the average distance to the first stop in the pattern and the average activity durations (main activity and first stop activity) for workers and non-workers for the relevant activity patterns.

In this table, the average working time (405.8 minutes = 6h45.8m) is reported as that of the activity associated with the evening commute. The time spent for the main activity in the evening pattern is, as expected, substantially larger than that of the main activity in the morning pattern. One can note that the average distances travelled during and morning and evening patterns are about half of that travelled in commuting. The main stop in the morning commute is closer home than that in the evening (as the distance of 7.4 km reported in the table is measured from the workplace).

Table 6 Spatial and duration characteristics of the activity pattern

	Morning	To work	Midday	From work	Evening
Workers					
Distance of activity from home [km]	5.3	9.0	-	10.6	6.2
Distance of first stop from base [km]	2.6	4.8	-	7.4	5.6
Duration of main activity [min]	37.4	(405.8)	-	(405.8)	87.5
Duration of first activity [min]	14.3	14.1	-	20.6	27.6
Non-workers	Before		Principal		After
Distance of activity from home [km]	4.5		13.7		6.8
Distance of first stop from base [km]	4.2		7.0		5.6
Duration of main activity [min]	40.7		130.0		45.0
Duration of first activity [min]	16.9		23.2		22.0

The duration of the main activity in the principal pattern (130 minutes = 2h10m) corresponds relatively well to a leisure activity or shopping trip, which were identified as the most frequent. The discrepancy between the durations of the main activities in the morning and evening patterns is smaller that for workers, which might reflect less stringent time constraints. The distances travelled for the principal pattern and even for the first stop in this pattern are relatively large especially compared to those in the morning and evening patterns.

5 Model estimation and results

The mode choice models presented here are tour based. As discussed above, this has advantages over a trip-based approach, as the behaviourally relevant unit of choice: the tour is addressed in this way. In addition, as shown above, most travellers do not change mode within a tour. The disadvantage of the tour-based approach lies in the description of the alternatives. In the analyses reported here it is assumed that a) the destinations do not change depending on mode and b) that the travellers do not switch modes within the tour, i.e. the tour is labelled by its main mode.

The unit of analysis is a single tour, all purposes are included. Each tour can be described by pattern level variables (position within the day), by tour level variables (main activity type, main activity duration, location type of the destination, number of stops, departure time, sum of previous travel times on the day), by level-of-service variables derived from the geo-codes and by the relevant networks (travel time and variable cost of travel). The person is characterised not only by the usual socio-demographics, but also by its long term commitments (car- and season ticket ownership) and habits (being the main user of a car, annual VMT, 24h minus the average time budget for activities; here the average duration between the first departure from home and the last return to home). After removing observations with missing values[2], in particular the Halle part of the data, the data set holds 5988 tours derived from 3478 person-days, 768 person-weeks, 145 individuals and 67 households. The decision variable is the main mode of the tour, defined at the mode used for the longest duration.

Four different types of models are reported in this paper.

The basic multinomial logit model (Ben-Akiva and Lerman, 1985), in which the utility that an individual i associates with an alternative a on choice c is expressed by:

$$U_{iac} = a_i\, x_{iac} + e_{iac} \qquad (1)$$

where x_{iac} is a vector of observed variables, a_i is a corresponding coefficient vector which may vary over individuals but does not vary across alternatives or time, and e_{iac} is an unob-

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[2] This consideration led to dropping the household income variable from the models, as we would have needed to work with imputed values for a substantial share of the sample.

served random term that captures all the effects not measured and a_i is assumed to be independent of e_{iac} and x_{iac}.

A logit panel data model (Revelt and Train, 1997) which accounts for the correlation across the observations belonging to the same group (person-day, person-week, individual or households). In this model the error term is partitioned into two components: $e_{iac} + e_{ac}$. The first component is assumed to be independently and identically distributed across alternatives and individuals for each observation, the second component is assumed to be independently and identically distributed across alternatives but equal for each observation of the same group (person-day, week, individual, household). This formulation accommodates the effect of state dependence on the choice of an alternative. Within the same group of observations per day the term is reversed specifically for the effect of previous choice on the actual choice. The model by individuals accounts for the correlations across the observations given by the same person. The model by household accounts for state dependence across members of the same family.

A mixed logit model (McFadden and Train, 1996) accommodating the heterogeneity to alternative characteristics and finally a mixed logit on panel data which accounts for both correlation within group and for heterogeneity. The main concept in this model formulation is that parameters vary over people.

Defining $a(\mu,?)$, where m is the mean and q the covariance of a, the IID specification across alternatives is relaxed. If we combine this error structure with the error component formulation by group we get a more flexible model, which incorporates heterogeneity in sensitivity to characteristics of the choice alternatives and recognizes correlations across the observations.

The models were estimated using Gauss 3.5 (Aptech Systems, Inc, 1999). The code was written by Kenneth Train at University of California, Berkley and is available on the web (http://elsa.berkeley.edu/~train/software.html).

An extensive set of variables was tested. A number of activity variables have been included: dummies related to the purpose of the main activity of the tour or to the number of stops within the tour. A time-budget related variable (24 hours – average time spent on activities – average time spent at home after the last arrival home) is included, as well as time-of-travel – related variables. In most cases, the new variables improve the model fits.

In the logit model (Table 7) we estimate 23 parameters and 4 alternative specific constants (ASC), all are significant and of the right sign. All the ASC are positive except for car passenger, that is in part explained by the fact that a large part of the population use public transport, bike or walk. The low percentage of car passengers is also related to the low percentage of tours whose main purpose is pickup/drop off, when comparing it with other urban survey (Cirillo and Toint, 2002). The value of travel time savings (VOT) is about 3.9 and 7.9 DM per hour depending on the model formulation (2.0-4.0 Euro/h), which is low compared to values (about 5 Euro for work tour) found in a European study comparing their values across the Union (TRACE, 1999). But again in this model all purposes are included (leisure and shopping activities are half of the tours considered). Among household variables, the home location in the core city is found to be positive for public transport use and the location in urban fringe is negative for walk and cycle, both significant. The number of adults in the household parameter is positive and significant for the utilities of car drivers and car passengers. On the individual level the effect of age is measured by dummy variables; individuals under 25 and between 50 and 65 tend to use public transport, individuals between 25 and 35 are mainly car users. Being a full time worker increases the probability to use public transport. The interaction term of sex and working status has been included following the example of Bhat and Koppelman, 1993 and was found to be significant. Being the main user of the car has a very strong effect on the mode choice together with the annual vehicle mileage. The main activity purposes of tours also are found important to explain travel behaviour, in particular if the main tour purpose is picking up or dropping someone off, individuals are more likely to use car, the purpose shopping decreases the utility of public transport and leisure increases it for cycling. The number of people participating in the tour increases the probability of using car (both as driver and passenger), as expected. The number of stops increases the probability of using car and decreases the probability of using public transport. The parameters of the activity based variables related to time (time budget and sum of previous travel times) are found to be negative and significant. An increasing time budget decreases car use and a larger sum of previous travel times reduces the probability of cycling and public transport use

The same specification was kept to estimate the panel data model, which accounts for correlation across observations. The values of the estimated coefficients do not change, but their t-statistics decrease significantly when the model accounts for choice repetitions across the same group (person-day, person-week, person and household). The lack of change in the log-likelihood function values can be explained by the high number of Halton draws per choice repetitions (125) used to estimate the models. This is consistent with what found by Bhat and Castelar (2002), although further investigations are needed on this point.

A similar specification was used to estimate the mixed logit model on panel data (in Table 8 we report the results of the mixed logit model accounting for correlation across tours for a given person-day). Just three variables were excluded (main user of a car, size of party and sum of previous travel times in the public transport utility function), because the full panel mixed logit specification did not converge with them. The main objective was to measure unobserved heterogeneity in the sensitivity to characteristics of the choice alternatives. We specify the parameters of travel time, travel cost and sum of previous travel times as log-normal variables; this distribution assumes that the coefficients are always positive, to turn them to negative we rescaled the variables by –1. This specification avoids the problem of the parameters being positive for part of the population. Time budget variable is normally distributed. Looking at the mixed logit model which accounts also for correlation across tour made on the same day we observe that two alternative specific constants (public transport and bike), age and full time status become insignificant, all the others keep the right sign and stay significant. The mean and the standard deviation of the parameters on the level of service and on activity time related variables are highly significant, indicating the presence of response heterogeneity. We also register a significant improvement in log-likelihood values (Table 9) from the logit model (although a direct comparison is not correct because of the different degrees of freedom in the two models) to mixed logit model on panel data, the best model in terms of Likelihood is the mixed logit accounting for correlation across the observations given by the same individual.

In Table 10, we compare the money values of time (VOT) and their confidence interval using the asymptotic t-test formulation proposed by Armstrong, Garrido and Ortuzar (2001). The upper and lower bounds for the interval are defined as follows:

$$V_{S,I} = \left(\frac{\theta_t}{\theta_c}\frac{t_c}{t_t}\right)\frac{t_t t_c - \rho t^2}{t_c^2 - t^2} \pm \left(\frac{\theta_t}{\theta_c}\frac{t_c}{t_t}\right)\frac{\sqrt{\left(\rho t^2 - t_t t_c\right)^2 - \left(t_t^2 - t^2\right)\left(t_c^2 - t^2\right)}}{\left(t_c^2 - t^2\right)}$$

where t_t and t_c correspond to the t-statistics for q_t and q_c respectively, t is the critical value of t given the degree of confidence required and sample size and r is the coefficient of correlation between both parameters estimated. It can be observed that the confidence interval derived from this formulation is not symmetrical with respect to the point estimate in the multinomial logit, but the two values are very similar for the other model specifications. Given the relatively large number of observations (5988), the size of the VOT confidence interval is quite smaller and the point estimate tends to the internal's mid-point, as expected.

Table 7 Mode choice model: Multinomial Logit

Variable	Mode Car driver		Car passenger		Public transport		Walk		Cycle	
Description of household										
Location in urban core					0.47	*				
Suburban location within city							-0.43	*	-0.43	*
Number of adults	0.10	*	0.10	*						
Description of person										
Age18-25					1.01	*				
Age25-35	0.35	*	0.35	*						
Age50-65					0.24	*				
Full time worker					0.20	*				
Female and Part time			1.03	*						
Married with children	0.69	*	0.69	*						
Main user of car	1.02	*								
Annual mileage (km/1000)	0.03	*								
Number of season tickets	-0.28	*								
Time budget (min/100)	-0.04	*	-0.04	*						
Description of situation										
Pick up/ Drop off	0.52	*	0.52	*						
Shopping					-0.69	*				
Leisure							-0.26	*	-0.26	*
Sum of Travel Times (min)					-0.01	*			-0.005	*
Size of party	0.81	*								
Number of stops	0.13	*			-0.14	*				
Alternatives										
Travel time (min) (generic)	-0.015	*	-0.015	*	-0.015	*	-0.015	*	-0.015	*
Cost (DM)(generic)	-0.112	*			-0.112	*				
Constants			-1.18	*	1.20	*	2.05	*	1.77	*
L(β)			-6959.32							
N			27							

$* \sim \alpha < 0.05$

Table 8 Mode choice model: Mixed Logit model on panel data (person-days).

Variable	Mode Car driver		Car passenger		Public transport		Walk		Cycle	
Description of household										
Location in urban core					0.86	*				
Suburban location within city							-0.62	*	-0.62	*
Number of adults	0.18	*	0.18	*						
Description of person										
Age18-25					0.97	*				
Age25-35	0.26		0.26							
Age50-65					0.22	#				
Full time worker					0.25	#				
Female and Part time			1.39	*						
Married with children	0.90	*	0.90	*						
Annual mileage (km/1000)	0.07	*								
Number of season tickets	-0.57	*								
Time budget (min/100) (mean)	-1.66	*	-1.66	*						
Time budget (s.d.)	1.16	*	1.16	*						
Description of situation										
Pick up/ Drop off	1.51	*	1.51	*						
Shopping					-0.89	*				
Leisure							0.26	*	0.26	*
Sum of Travel Times (min)(mean)									-4.61	*
Sum of Travel Times (s.d.)									2.11	*
Number of stops	0.35	*			-0.18	*				
Alternatives										
Travel time (min)(mean) (generic)	-0.231	*	-0.231	*	-0.231	*	-0.231	*	-0.231	*
Travel time (s.d.) (generic)	0.322	*	0.322	*	0.322	*	0.322	*	0.322	*
Cost (DM)(mean) (generic)	-3.334	*			-3.334	*				
Cost (s.d.) (generic)	1.196	*			1.196	*				
Constants			-2.24	*	-0.729	*	0.428		-0.199	
$L(\beta)$			-6794.63						* ~α < 0.05	
Number of parameters			28						# ~α < 0.10	

Table 9 Models: goodness-of-fit statistics

Parameters	MNL	MXL	MXL on panel data (person-day)	MXL on panel data (person-week)	MXL on panel data (person)	MXL on panel data (house-holds)
Log-likelihood at zero	-8800	-8800	-8800	-8800	-8800	-8800
Log-likelihood with constants only	-7870	-7870	-7870	-7870	-7870	-7870
Log-likelihood at convergence	-6965	-7178	-6795	-6065	-5621	-6177
Number of parameters excluding constants	23	24	24	24	24	24
Adjusted $\bar{?}^2$	0.113	0.085	0.134	0.226	0.283	0.212

Table 10 Models: money values of travel time savings [DM/h]

Variable	MNL	MXL	MXL on panel data (person-day)	MXL on panel data (person-week)	MXL on panel data (person)	MXL on panel data (house-holds)
Upper limit	11.71	2.02	5.14	4.54	5.82	8.09
Lower limit	5.17	1.22	3.17	2.22	2.09	-0.92
Range	6.55	0.91	1.97	2.32	3.72	9.02
Midpoint	8.44	1.67	4.16	3.37	3.95	3.58
Point estimate	7.93	1.64	4.15	3.36	3.88	4.29
?	-0.013	0.063	0.243	-0.027	-0.201	0.904
t	-6.37	-7.09	-8.03	-5.86	-4.38	-1.66

6 Model application

The model has been applied to predict mode shares for classes of individuals, on the bases of their household and individual characteristics. The standard sample enumaration approach has been used, by which the choice probabilities of each decision maker in the sample are aver-aged over the individuals belonging to the class considered. However, if the model is run on sub-classes with different characteristics than the sample used for estimation, then the value of the alternative specific constants has to be reestimated. This procedure allows us to consider the fact that the mean of included variables for the class for which forecasts are made is not the same as those in the sample from which the estimation was made. The value of the other coefficients reflect the behavioural importance of the variables, no reestimation is required to accommodate them (Train, 1990).

The predictions are differentiated by the purpose of the tour main activity (work, pickup/drop-off, shopping and leisure).

Table 11 shows predictions for an individual living in the built-up area of Karlsruhe, older than 25 without a season ticket. It must been mentioned that Karlsruhe has got an excellent public transport system and that cycling is very common especially in the built-up area. For this sub-class it appears that the use of private car is limited to 40% (except for the pickup drop-off purpose) and that the low percentage of users of public transport is explained by the high percentage of cyclists.

Table 11 Predictions for an individual living in the built-up area, older than 25, without season ticket.

Mode	Work	Pick-up/Drop-off	Shopping	Leisure
Car driver	38.5	44.5	30.9	40.9
Car passenger	6.1	1.2	3.9	5.1
Public transport	9.5	11.3	10.2	10.4
Walk	16.7	3.6	15.9	9.7
Cycle	29.2	39.4	39.1	33.9

In Table 12 we study the behaviour of people living in the suburban part of the city, employed full time. The percentage of the car users is higher (from around 46% for work tour to 50% for shopping tours), but we register also a more frequent use of the public transport (which is in average about 20% of the mode share). Walking and being car passenger is not very popular, while cycling is still chosen by around 20% of the population in this class.

Table 12 Predictions for an individual living in the suburban part of the city and employed full time

Mode	Work	Pick-up/Drop-off	Shopping	Leisure
Car driver	45.9	46.5	51.8	50.0
Car passenger	6.2	1.2	2.7	2.7
Public transport	20.4	22.8	18.8	18.8
Walk	7.6	1.1	4.4	4.4
Cycle	19.9	28.4	22.3	22.3

Finally, we predict the mode choice for women employed part-time and living in the suburb. Although the percentage of women choosing the private car is very high, the number of car passengers predicted is much more significant than for the previous classes (18% for work tours and around 20% for leisure tours). Public transport is chosen by an average of 15% of this class. We register also an high percentage of women walking to their work place, while cycling is definitely less popular among them.

Table 13 Predictions for a woman employed part-time, living in the suburban part of the city

Mode	Work	Pick-up/Drop-off	Shopping	Leisure
Car driver	36.6	46.3	47.8	45.9
Car passenger	18.1	7.2	11.2	19.8
Public transport	15.8	15.6	18.6	14.3
Walk	13.8	9.0	7.6	5.6
Cycle	15.7	21.9	14.8	14.4

7 Conclusions

The paper has presented a very detailed model of main mode choice at the tour level. The explanatory variables were derived from the characteristics of the household and the person and of the alternatives. Most importantly though the choice situation and the tour were described in detail, including variables previously not used: average out-of-home time budget and the sum of pervious travel times at the point of departure for the tour. The first of these two is only possible because of the underlying 6-week diary. The second is available in principle for one-day diaries are as well. In addition, the inclusion of pre-commitment variables specified these models as short-run choice models.

Accounting for the within-group error-term correlations changes the conclusions about the significance of different variables. The lack of significance for the person characteristics for the person-based mixed model is particularly noteworthy. The taste differences allowed in the mixed logit absorb the effects of the socio-demographic variables, which are otherwise noticeable.

One by-product of these changes are related changes in derived rations, such as the value of travel time savings. The values derived for the best-fitting model are surprisingly low (point estimate 3.88 DM/h; 3.95 midpoint of the confidence interval), which raises interesting questions for evaluation. Should this be based on short-run choice or should it be based on longer run choices, e.g. the trade-offs made for the ownership/pre-commitment decisions or even the trade-offs made at the location choice decision.

The use of commitment variables (being main user of a car, level of car driving, ownership of season tickets) improved the model. One could argue that this success is trivial, but it highlights the question of choice of the proper time horizon for a model. In this case, the models address the short term choices for a tour, which would be suitable in a dynamic simulation of activity behaviour. This highlights the need to specify the time-horizons of choice models carefully. This is unfortunately rarely done explicitly with the results that promising variables are omitted or equally problematic unsuitable variables are included.

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