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September 1991  
Working Paper, No. 21

**The University of California  
Transportation Center**

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**A Simultaneous Dynamic Travel and Activities  
Time Allocation Model**

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## **1. INTRODUCTION**

In this paper a model is developed and estimated empirically of the allocation of time to out-of-home activities and travel. The model has three important characteristics.

First, the allocation of time to out of home activities by individuals is the key concept in the research reported here. Since there exist interdependencies among time usages for different activities, the joint distribution of all relevant out of home activity times has to be taken into account. Consequently the model developed is multivariate.

Second, travel is a derived demand. The amount of travel is the result of the spatial activity behaviour of the individual. Of course, the exact relation between activity performance and travel demand is highly complex. The spatial dispersion and quality of activity locations and the scheduling of activities by individuals are both important elements that need to be studied in order to predict total travel demand from a given activity pattern. Here a much simpler approach is taken. It is assumed that total travel time expenditure over a certain time period (i.e. one week) for an activity is proportional to the total amount of time engaged in that activity.

The third main feature of the model is its longitudinal character. Longitudinal data have a number of advantages over cross-sectional (see e.g. Hensher, 1985; Davies and Pickles, 1985; van Wissen and Meurs, 1989). From a statistical point of view it allows the estimation of model parameters conditional on non-observed stationary characteristics and individual taste variations. From a theoretical point of view longitudinal data are necessary in order to identify and estimate dynamic processes. In this study only the statistical advantages of longitudinal data will be used.

This paper is organized as follows. In section two an overview is given of earlier related work on the allocation of time and the travel consequences. In section three the model methodology will be presented. Next, in section four, the data will be described briefly. Section five contains the empirical results of the model estimation. These results are evaluated and some conclusions are drawn in section six.

## **2. THE ALLOCATION OF TIME OVER ACTIVITIES AND TRAVEL**

The way people use their time has been the subject of many studies in various fields of social science. It seems that many social processes can be measured, at least indirectly, by the amount of time people spend in various types of activities. Each human activity takes time and the various ways in which people use their time sheds light on the intensity or the outcomes of these social processes. That is why the study of the allocation of time was taken up by sociologists (Szalai, 1973), economists (Becker, 1965; DeSerpa, 1971; Gronau, 1977), geographers (Hägerstrand, 1970; Chapin, 1974; Thrift, 1977; Parkes and Thrift, 1980) and transportation scientists (Allaman et al., 1982; Kitamura, 1984; Damm and Lerman, 1981; Pant and Bullen, 1980; N.V.I., 1978). For economists, the way households use their time is an indicator of various household production processes (Walker and Woods, 1976). In the economic theory of household

production (Becker, 1965; Gronau, 1977) time and goods are production inputs for the production of household commodities. Households allocate their available time over the market sector (work), home production (maintenance, care) and consumption activities, such that total utility derived from the consumption of produced commodities is maximized. In time-space geography developed by Hägerstrand (1970) the time-space prism is the central concept that constrains people's activity behaviour. Chapin (1974) sees the progression through the life cycle as the main variable shaping different activity patterns in time and space.

In transportation science time has been used as a means to improve travel forecasts (Kirby, 1981). Several developments can be discerned. First, some micro-economic models of travel demand have been developed using elements of household production theory (De Donnea, 1971). Other theories of time allocation in activity making have been developed by Damm and Lerman (1981) and Kitamura (1984). They studied the decision to engage in an activity and the amount of time spent in the activity simultaneously. Kitamura developed a theory of random utility maximization that can be applied to the time allocation problem. Since their analyses use one day activity data there is a significant probability of non-participation on a given day. Next, the notion of stable travel budgets has been a key concept in many studies of transportation (for an overview, see Gunn, 1981). Zahavi (1979) introduced the idea of a fixed travel time budget and Golob et al. (1981) developed a theoretical model based on this idea. Others (e.g. Tanner, 1981) assume a generalized travel expenditure budget, consisting of both time and money outlays. In generalized travel expenditure studies the value of travel time is a key concept (Bruzellius, 1979).

In travel budget studies no reference is made to activity times as such. A number of studies have looked at the allocation of activity times in relation to mobility. Pant and Bullen (1980) calculated the correlations between various out of home times and travel time and related this to socio-economic characteristics of the respondents. Working time appeared to be the most important variable explaining out of home time by other activities. They also found that there are significant correlations between travel time and activity duration, although for working time the relationship was non-linear, indicating decreasing travel times after some high threshold level of working time. Allaman et al. (1982) studied time expenditures for various purposes in a multivariate model and also looked at the resulting mobility. Life cycle and car ownership levels turn out to be key explanatory variables. The model developed by N.V.I. (1978; see also Rheijs and Zondag, 1988) uses a two stage procedure to forecast the number of trips from activity time data. First, travel time is modeled as a function of activity times. Next, trips are estimated from these travel time forecasts. The model to be presented in the next section also has an activity component and a derived travel component.

### 3. A LONGITUDINAL SIMULTANEOUS EQUATION SYSTEM

The model presented in this section has some similarities with the model developed by Allaman et al. It is a simultaneous linear equations system of various activity times and travel time containing structural effects among the activity times, structural effects of activity times to travel time and conditional effects of exogenous variables on activity times and travel time. In addition, the model is longitudinal: the same variables are measured at five points in time. The longitudinal character of the data has some statistical advantages compared to cross-sectional data. This will become clear in the following sections. First, we will discuss the various components of the model. Next, all components will be combined in a longitudinal structural equations system of activity and travel time expenditures.

The endogenous variables are various activity times and travel time. Suppose we have  $l$  different activities, with activity times denoted by  $a_i$ ,  $i=1,\dots,l$ . We are only interested in a number of out-of-home-activities, work, shopping, recreation, etc. (for the exact definition of the variables used, see section four). Thus, total activity times do not add up to the total length of the survey period. Next, we have travel time as an additional endogenous variable, denoted by  $m$ . Because of the longitudinal character of the data each variable has a subscript  $t$ . The activity times and travel time for period  $t$  can be organized in a vector  $\underline{a}_t$  of size  $l+1$ :

$$\underline{a}_t = \begin{bmatrix} a_{1t} \\ \vdots \\ a_{it} \\ \vdots \\ a_{lt} \\ m_t \end{bmatrix}$$

and all time dependent vectors can be stacked into a vector  $\underline{a}$ :

$$\underline{a} = \begin{bmatrix} \underline{a}_1 \\ \underline{a}_2 \\ \underline{a}_3 \\ \underline{a}_4 \\ \underline{a}_5 \\ \underline{\alpha} \end{bmatrix}$$





on the time variables in  $\underline{a}_t$  are given in the matrix  $r_t$ , with  $l+1$  rows and  $K$  columns. Next, we have  $L$  time independent variables organized in the vector  $\underline{z}$ . Since there is no intertemporal variation, the only source of variation that can be explained by these variables is variation across individuals. Thus, we can think of these variables as individual specific constants that do not change over time.

Turning to the error structure of the model, a similar distinction between time varying and time independent error components can be made. With each endogenous variable indexed  $i$  measured for individual  $j$  at time  $t$ ,  $y_{ijt}$ , is associated an error term  $\sigma_{ijt}$ . This error term can be thought of as generated by various sources: an individual specific time invaring component  $\mu_{ij}$  and a random component  $\varepsilon_{ijt}$ :

$$\sigma_{ijt} = \mu_{ij} + \varepsilon_{ijt} \quad (2)$$

Thus, leaving out, as before, the individual subscript  $j$ , we have two time invariant elements in our model: the exogenous variables  $\underline{z}_i$  and the random error component  $\mu_i$ . These can be combined in the time invariant latent variable  $\alpha_i$ :

$$\alpha_i = \sum_{p=1}^L \delta_p z_p + \omega_i \quad (3)$$

The  $\delta$ 's are the regression coefficients of the time invariant exogenous variables on the latent constructs  $\alpha$ . The  $\omega$ 's are similar to random effects in variance components models where an individual-specific time invariant random element is identified (see e.g. Chamberlain, 1984; Hsiao, 1986; Hensher, 1988; Meurs, 1988, 1989). This term captures omitted time invariant variables, individual taste differences etc. The longitudinal character of the data makes it possible to decompose the error term in an individual specific component and a purely random component according to eq. (2). Thus, it removes bias in the estimates of the included variables that might be due to these omitted variables or taste differences.

The time invariant regression coefficients  $\delta$  can be organized in a  $(l \times L)$  matrix  $\Delta$ . Taking the  $r_t$  and  $\Delta$  matrices together, we can form the block-diagonal matrix of regression coefficients  $\Gamma$ :

$$\Gamma = \begin{bmatrix} \Gamma_1 & & & & & \\ & \Gamma_2 & & \phi & & \\ & & \Gamma_3 & & & \\ & & & \Gamma_4 & & \\ \phi & & & & \Gamma_5 & \\ & & & & & \ddots \\ & & & & & & \Delta \end{bmatrix}$$

The matrix is block-diagonal because there are no lagged effects. Therefore, any non-diagonal submatrix  $r_{t',t}$ , where  $t' \neq t$  is zero, which is denoted by  $\phi$ .

Combining all the elements we can now specify the complete model as follows:

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ \alpha \end{bmatrix} = \begin{bmatrix} B_1 & & & & & \\ & B_2 & & & & \\ & & B_3 & & & \\ & & & \emptyset & & \\ & & & & B_4 & \\ & & & & & B_5 \\ & & & & & & I \end{bmatrix} * \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ \alpha \end{bmatrix} + \begin{bmatrix} \Gamma_1 & & & & & \\ & \Gamma_2 & & & & \\ & & \Gamma_3 & & & \\ & & & \Gamma_4 & & \\ & & & & \Gamma_5 & \\ & & & & & \Delta \end{bmatrix} * \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ z \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \omega \end{bmatrix}$$

(4)

or, more compactly:

$$\underline{a} = B \underline{a} + \Gamma \underline{x} + \underline{\varepsilon} \tag{5}$$

The matrix of structural effects, B, incorporates both the causal effects among the time expenditures,  $B_t$ , for each of the five time periods, and the effects of the latent time invariant factors  $\alpha$ , including the stationary exogenous variables and the random effects.

The submatrices I in B are identity matrices with size (l + 1) and account for the effects of the latent variables. The  $\alpha$  vector has l + 1 elements, where the first l elements are the latent time invariant factors for each of the activity times and  $\alpha_{l+1}$  the latent factor for travel time. There are no structural effects among the latent variables assumed in the model although this restriction could be easily relaxed by incorporating an additional non-zero submatrix in the lower right corner of B. The  $B_t$  submatrices with the structural effects among the time expenditure variables have the form:

$$B_t = \begin{bmatrix} H_t & \underline{0} \\ \underline{\pi}_t & \emptyset \end{bmatrix}$$

where H and  $\underline{\pi}$  are as described above and  $\underline{0}$  is a vector of length l with all zero's.

We assume that the error term of the latent variable  $\alpha_i$ ,  $\omega_i$  has a normal distribution with zero expectation and variance  $\mu_i$ . The joint distribution of the  $\omega$  error term vector of all latent constructs of the l + 1 time expenditure variables is multivariate normal with expectation zero and variance-covariance matrix M (l + 1 x l + 1):

$$\underline{\omega} = N(0, M) \tag{6}$$

Similarly, we assume that the distribution of  $\underline{\varepsilon}_t$  is multivariate normal:

$$\underline{\varepsilon}_t = N(\underline{0}, \theta_{tt'}) \quad (7)$$

Serial correlation can be introduced in the model by specifying submatrices  $\theta_{t,t'}$ , with  $t'=t-1, \dots, 1$ . The  $\theta_{tt'}$  and M matrices can be combined into one variance-covariance matrix  $\theta$  of size  $(6I+6)$ :

$$\theta = \begin{bmatrix} \theta_{1,1} & & & & & \\ \theta_{2,1} & \theta_{2,2} & & & & \\ \theta_{3,1} & \theta_{3,2} & \theta_{3,3} & & & \\ \theta_{4,1} & \theta_{4,2} & \theta_{4,3} & \theta_{4,4} & & \\ \theta_{5,1} & \theta_{5,2} & \theta_{5,3} & \theta_{5,4} & \theta_{5,5} & \\ & & \emptyset & & & M \end{bmatrix}$$

The errors of the latent variables are uncorrelated with the error terms of the time variables.

The model is specified as a moment (variance-covariance) structure and can be estimated by minimizing the function given by:

$$F[\underline{\tau}] = \log |\Sigma| + \text{trace}(\Sigma^{-1}S) - \log |S| - (p+q) \quad (8)$$

with respect to the parameter vector  $\underline{\tau}$ . Here,  $\Sigma$  is the theoretical variance-covariance matrix and S is the sample variance-covariance matrix. p and q are the number of y- and x-variables respectively. If the distribution is multinormal this yields maximum likelihood estimates which are efficient in large samples. At the minimum level, the value  $N \cdot F$  (N being the sample size) is a measure of goodness-of-fit. In large samples this measure is distributed as  $\chi^2$  with degrees of freedom equal to  $\frac{1}{2}p(p+1) + pq - s$ , where s is the number of free parameters in  $\underline{\tau}$ . Standard errors of  $\underline{\tau}$  can be obtained from the matrix of expected second order derivatives of F at the minimum.

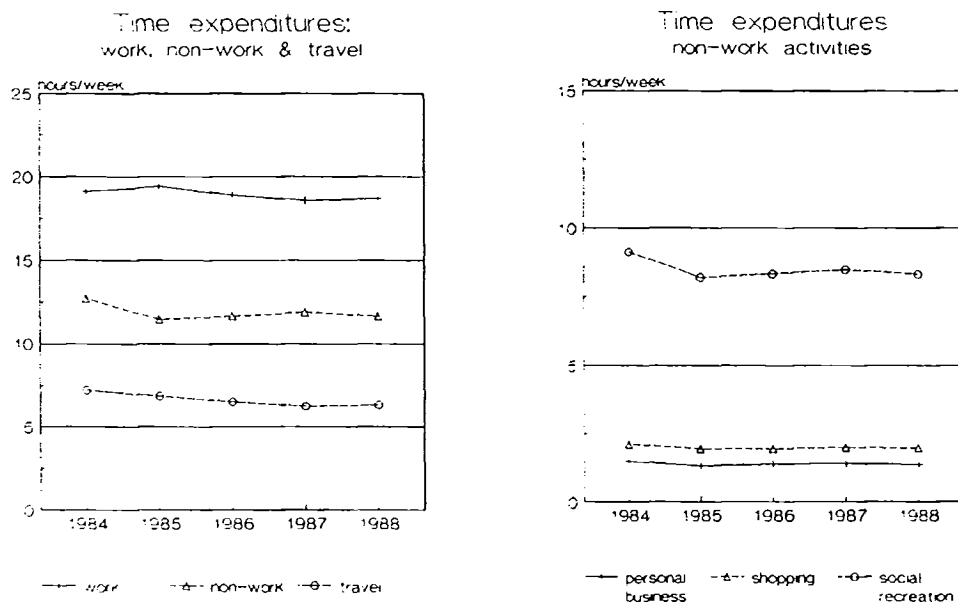
Details of the estimation procedure for these types of models can be found in Jöreskog (1973, 1977, 1979) and Jöreskog and Sörbom (1977, 1987).

#### 4. THE LONGITUDINAL TIME EXPENDITURE DATA

The data used in this study come from the Dutch mobility panel (Golob et al., 1986; van Wissen and Meurs, 1989). This is a longitudinal travel survey whereby respondents are asked annually to record their trips during a seven day period. The activities and their characteristics can be inferred from the trip information since the activity at the destination of every trip is known. Activity times can be inferred from

trip starting and ending times. Other survey methods focus essentially on the activity durations and sequence (see e.g. Knulst and Schoonderwoerd, 1983) and are probably more accurate. However, these purely activity oriented surveys do not contain detailed travel information.

For the present purposes five panel waves were used: the waves recorded in one week in the month march of 1984 through 1988. A subsample was taken to include the respondents who participated in all five waves. Further, the subsample was restricted to non-retired heads and housepersons of households with two or more persons. One parent household were also excluded so life cycle differences within the sample are mainly defined in terms of ages and the number of children. Out of these 770 heads and housepersons 4 were dropped because of data errors so that a sample size of 766 remained. Four out-of-home activities were used in the analysis: work, personal business, shopping and leisure (recreation and visits). In figure 1a the total amount of work, non-work out-of-home time and travel time are depicted. In figure 1b the non-work activities are broken down in personal business, shopping and leisure. Work is the most time consuming out-of-home activity, followed by social recreation. On average people spend approximately 7 hours per week travelling.



It is clear that there is non-random variation over time. Non-working activity times and travel time decrease between wave one and two. This is most likely due to panel biases in the data: respondents tend to respond less accurately their mobility behaviour with increasing panel participation (for a detailed analysis of this phenomenon on these data: see Meurs et al., 1989). Therefore, trip times and some activities are downward biased with increasing panel participation. However, this analysis is not concerned with mean time expenditures per se, but with second order moments (variances and covariances), so this panel bias

does not hinder the analysis very much.

A number of exogenous variables were available. After a series of univariate analyses that included analysis-of-variance and regressions, a small set of relevant variables was chosen. The following list gives the variables, the original categorization and the categories used in the model:

- household income (4 categories. Only the highest income group is an important conditioning variable)
- life cycle (4 categories: young couples without children; couples with children under 12 years; couples with child(ren) over 12 years; older households without children. Only the first two categories are significantly related to time expenditures)
- number of children
- position in the household (2 categories: head; non-head)
- driver's license (2 categories: yes; no)
- region of residence (4 categories: large cities; middle sized towns; suburbs; other. Only the first category is important)

These variables were used in the longitudinal modeling of time expenditures. The next section describes the model results.

## 5. MODEL RESULTS

In this section, a basic model model is presented of time expenditures, whereby it is assumed that the structural relations among the time expenditures and the travel time, and the conditioning effects of life cycle, income etc. are stable over time. This means imposing the following constraints on the model parameters:

$$B_t = B^*, r_t = r^*, \text{ for } t=1,\dots,5 \quad (9)$$

So, the effects of time expenditures upon each other, and the travel generating effects of activities are assumed constant over time. The influence of the exogenous variables is also assumed to be stable over time. This is a very parsimonious model whereby only the error terms in  $\theta$  are free across time. The validity of the restrictions will be tested by comparing the model fit of the unrestricted model with the (nested) restricted basic model.

First we turn to the structural parameters among the time expenditures and between activity times and travel time in the structural effects matrix  $B$  (table 1). There are only three significant effects among the activity times and it can be noted that the structural effect of working time on all other activities is negative. No significant structural effects can be found among the other activities and these parameters are constrained to zero. The negative effect on leisure time is much stronger than on shopping and personal business. Table 1 also shows, in the bottom row of the matrix, the vector  $\underline{x}$ , i.e. the travel generating effects of the activity times. The coefficients are the amount of time spent traveling for an hour spent in an activity. Therefore, these coefficients can be interpreted as a travel intensity measure. Personal business is the most travel intensive, followed by shopping. These activities are characterized by relatively short durations which

involve trip making. Working has a relatively low value of travel intensity, which is due to the long duration. Leisure activities fall in between these extremes. Thus, according to these figures, a decrease in working time would lead to an increase in the non-work activities. The direct effect of decreasing work on travel time would be negative but this would be (partly) compensated for by the indirect effect through the increase in non-working activity times. If we restrict ourselves to the matrix  $B^*$  given in table 1 it is possible to calculate the indirect and total effects of working time on travel time. Indirect and total effects are given by:

$$\text{indirect effects: } (I - B^*)^{-1} - I - B$$

$$\text{total effects: } (I - B^*)^{-1} - I$$

Using these formulas to compute indirect and total effects we observe that the indirect effect from working time to travel time is indeed negative: -0.059, and the total effect is therefore -0.011. Thus, a decrease in working time would lead to an increase in travel time.

Next, we turn to the effects of the exogenous variables on time expenditures. Time varying exogenous variables are household income, lifecycle and the number of children. Table 2 gives the estimated effects of these variables on the activity times and travel time. The following significant effects can be discerned:

- being in the highest income group is positively related to working time, shopping time and travel time. It is negatively related to leisure time. Of course, the working time - income relation is not modeled adequately here: income results from working activities and not vice versa. The ordinal nature of the income variable makes the estimation of such a relation more difficult since it is non-linear (see Golob, 1989, for an example of income as an ordinal endogenous variable)
- persons in young households without children spend more time working and in leisure than households with children and older households
- persons in households with young children devote more time to personal business but less time to shopping
- an increase in the number of children in the household leads to an increase in time spent for personal business and to a decrease in the amount of time in leisure and traveling. The decrease in leisure time is most profound: for each additional child in the household out-of-home leisure time decreases on average with 1.13 hour per week. In other analyses (van Wissen, 1989) it is shown that this decrease in leisure is not evenly distributed among the household members.

In addition to time varying exogenous variables there are a number of stable variables  $z$  that influence the time structure, as given in eq. (3). Their effects on the time invariant latent variables as given in table 3 are the following:

- Being a head in the household is significantly and positive related to working hours, leisure time and travel time. It is negatively related to personal business.
- License holding is positively related to working hours, personal business and travel time.
- Persons living in large cities spend more time in personal business.

Table 1: Structural effects among time expenditures and travel time (matrix  $B^*$ )

---

	W	PB	S	L
W	$\begin{bmatrix} -0.020 & & & & \\ -0.021 & & & & \\ -0.036 & & & & \\ 0.048 & 0.201 & 0.176 & 0.104 & \end{bmatrix}$			
PB				
S				
L				
T				

W = Work                                      PB = Personal Business  
 S = Shopping                                  L = Leisure  
 T = Travel

---

Table 2: Effects of time varying exogenous variables on activity times and travel time (matrix  $\Gamma^*$ )

---

	INC	YOC	YKD	NKD
W	$\begin{bmatrix} 0.325 & 0.349 & & & \\ & & 0.024 & 0.015 & \\ 0.026 & & -0.017 & & \\ -0.080 & 0.111 & & -0.113 & \\ 0.027 & & & -0.014 & \end{bmatrix}$			
PB				
S				
L				
T				

W = Work time                                  PB = Pers. business time  
 S = Shopping time                              L = leisure time  
 T = Travel time  
 INC = high income group  
 YOC = young households no children  
 YKD = households with only young children (< 12Y)  
 NKD = number of children in household

---

Table 3 Regression coefficients and error variance of individual specific latent variables (matrix  $\Delta^*$ )

	HD	LIC	CIT
$\alpha_W$	2.352	0.552	
$\alpha_{PB}$		0.058	0.067
$\alpha_S$	-0.094		
$\alpha_L$	0.111		
$\alpha_T$	0.135	0.054	

W = Work                                      PB = Personal Business  
 S = Shopping                                    L = Leisure  
 T = Travel  
 HD = Head (1=head; 0=non-head)  
 LIC = Drivers license (1=yes; 0=no)  
 CIT = Living in large cities (1=yes; 0=no)

The third component of the model is the error variance-covariance matrix  $\theta$ . The only non-zero error terms are the error variances and lagged error terms of the time variables. In table 4 the total variance of each of the time variables is decomposed in terms of explained variance, random time invariant effects and residual variance. The random time invariant effect of the time expenditure variables is the residual variance of the latent variables  $\alpha$ . In column (4) these random time invariant effects are expressed as a percentage of the total residual variance. Unobserved time invariant variables play an important role in the explanation of working time (about 70 % of the total residual variance) and travel time (about 50 % of the total residual variance). This means that additional explanatory variables for the amount of working time and mobility are largely static variables that pertain to the whole time period. A possible set of variables in this case is time persistent habits. This large influence of permanent effects on work and travel together with the relatively high  $R^2$  values implies that these time expenditures are to a high degree non-random. The time invariant effect plays a much smaller role in the determination of time for the non-work activities. The random element in these variables is in general much larger, as can be seen from inspecting the  $R^2$  values.

The total fit of the model, as given in eq. (8) is 1044.88 with 822 degrees of freedom. Although this  $\chi^2$  value is above the critical value of 891 at the 5 percent level the total fit cannot be judged unsatisfactory. First we may note that the distribution is only asymptotically  $\chi^2$ . Second, the model, although highly restrictive, shows no strong signs of "stress", as indicated by the modification indices of the restricted coefficients. The modification index of a coefficient is the expected increase in the log-likelihood (eq. (8))



**Table 4: Variance decomposition of time variables**

VARIABLE		VARIANCE DECOMPOSITION:				
		(1) Total	(2) Residual	(3) Random effect	(4) (3) as % of (2)	(5) R <sup>2</sup> 1 - [(2)/(1)]
Work	t=1	3.894	1.246	0.891	71.5	0.68
	t=2	3.831	1.259		70.8	0.67
	t=3	3.770	1.260		70.7	0.67
	t=4	3.754	1.255		71.0	0.67
	t=5	3.650	1.244		71.6	0.67
P.Bus.	t=1	0.063	0.055	0.007	12.7	0.14
	t=2	0.053	0.044		15.9	0.17
	t=3	0.075	0.066		10.6	0.12
	t=4	0.073	0.063		11.1	0.12
	t=5	0.063	0.055		12.7	0.14
Shopping	t=1	0.080	0.064	0.008	12.5	0.19
	t=2	0.066	0.051		15.7	0.23
	t=3	0.058	0.045		17.8	0.25
	t=4	0.052	0.037		21.6	0.29
	t=5	0.045	0.031		25.8	0.32
Leisure	t=1	0.709	0.564	0.126	22.3	0.21
	t=2	0.665	0.498		25.3	0.23
	t=3	0.771	0.622		20.3	0.25
	t=4	0.831	0.675		18.7	0.18
	t=5	0.804	0.662		19.0	0.18

if that coefficient is released (see Jöreskog and Sörbom, 1984). This can be tested also by releasing the constrained parameters. The model described here is highly restrictive: all coefficients in the B and r matrices are constrained to be equal across time. By releasing all these constraints we loose 72 degrees of freedom. The model fit is **963.29** with 750 degrees of freedom. The difference in fit is **81.59**, which is not a significant improvement in fit at the  $\alpha=0.90$  level. Thus, the joint release of the time equality constraints in the structural matrix B or in the regression matrix r does not give a significant better fit to the model. Therefore we conclude that the model with time restrictions on the structural effects among the time expenditures and equal conditioning effects of the exogenous variables is the most parsimonous and gives a reasonable fit to the data.

## 6. CONCLUSIONS

In this paper a model for the joint allocation of time to various out-of-home-activities and travel time has been presented. The development of this model was motivated by the observation that the usual assumption in travel demand theory, that mobility is a derived demand, is not substantiated in empirical

travel demand models. Therefore, in the model developed here travel time is the result of the joint allocation of individual time to work and non-work activities. The simultaneous nature of the model makes it possible to calculate both direct and indirect effects of changes in time expenditures. The direct effect of a decrease in working hours is less travel time. However, less working time has a positive effect on the other activity times and hence a positive indirect effect on travel time. Therefore, the total effect of decreasing working time on travel time is an increase in travel time.

The results indicate that the non-work activities are more travel intensive than work. The amount of travel time per hour of personal business, shopping or leisure is much greater than that generated by work. Due to the longitudinal character of the model it could be shown that the model structure is stable over the five time periods investigated. A parsimonious model could be estimated satisfactory with identical linkages for each of the five time periods. The longitudinal analysis also showed that working time and travel time are to a large degree determined by unobserved individual specific variables that do not change over time. This non-randomness of these processes is in principle a good starting point for possible policies aiming at influencing mobility levels. The other activities are to a higher degree determined by random effects across time and individuals.

These results are of potential interest for policy making, but further research should include at least two directions. First, travel time is not differentiated by travel mode. Therefore it cannot be concluded whether changes in time allocations between work and non-work activities will generate more car mobility or not. Second, the distribution of travel time over the day should be included in the analysis. Congestion is highly concentrated in time due to the timing of working hours. Although work is not very travel intensive it generates travel at specific times of the day. A change in the allocation of time from work to non-work may result in a more even distribution of travel demand over the day. However, other analyses with the same data (BGC, 1988) have indicated that a significant share of the mobility in peak hours is non-work related.

The link between activity times and mobility time is assumed to be linear. This is a very simple assumption and probably needs refinement. Despite this simplicity the explanatory power of the model for travel time is reasonably good: 0.50 to 0.60. Other analyses (not reported) which replaced travel time by the total number of trips showed similar results. Nevertheless, the exact nature of activity times and mobility is a complex one, where locational factors, accessibility and the level of service of various modes play a role. This remains an important topic for future research in activity analysis.

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