A MODEL OF SPATIAL STRUCTURE, ACTIVITY PARTICIPATION AND TRAVEL BEHAVIOR

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Abstract

In recent years many studies have addressed the relationship between land use and travel behaviour. At the same time, the notion that travel demand stems from activity demand has been explicitly incorporated into activity-based models. The role of spatial context in the activity-based approach has, however, been largely neglected. This paper has explored the influence of spatial variables on personal activity and travel behaviour, controlled for personal and household variables. For this purpose a structural equation model was developed to simultaneously estimate direct and indirect causal relationships. The model was based on two-day diary data that was collected in the Netherlands. The model fit was good, as was the explained variance between the activity and the travel variables. Significant relationships emerged between the activities themselves and with trip generation and travel time demand. The diverse socio-demographics exercised direct and indirect influences on the endogenous variables. The spatial variables exercised only a weak but nonetheless significant influence on the activity and travel variables. One (tentative) conclusion is that indirect effects can steer a total effect in another direction, for example, though density has no direct effect on travel time, the total daily travel time still increases because of the extra trips in high-density areas.

Keywords: Land use; Activity and travel behaviour; Structural equation model
Topic Area: F1 Transport and Spatial Development

1. Introduction

In recent decades, academics have been trying to understand whether and, if so, to what extent, travel behaviour is determined by the characteristics of the built environment. The aim of their research was to find ways of influencing travel behaviour by manipulating urban form, and to contribute to policies that reduce the externalities of transport. Policies that aim at influencing travel by means of spatial planning and design try to reduce distances between locations and increase the urban population base for public transport. It is expected that, consequently, travel distances are reduced and mode choice is shifted towards non-motorized and public transport. Careful testing is needed because spatial planning is a lengthy process which cannot be easily reversed and which has a deep impact on residential environments. To date, a lively and expanding body of academic literature is available. Some studies suggest that urban form has strong effects on travel behaviour (*e.g.* Ewing, 1995; Frank and Pivo, 1994; Meurs and Haaijer, 2001) but others have found only

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limited evidence (*e.g.* Cervero and Kockelman, 1997; Kitamura *et al.*, 1997; Stead, 2001; Snellen, 2002) or have even concluded that there is virtually no effect at all (*e.g.* Boarnet and Sarmiento, 1998; Crane and Crepeau, 1998; Bagley and Mokhtarian, 2002). It is remarkable that, in the Netherlands, there are only a few empirical studies, despite the ambitious policy efforts since the 1970s (Van Wee and Maat, forthcoming).

Most of the research on this issue relates personal and residential characteristics directly to travel behaviour variables. However, it neglects the common understanding that travel is derived from the activities in which individuals and households engage and thus cannot be understood independently of these. Theories on activity participation assume that the relationship between personal characteristics and travel behaviour is partly indirect, namely that it operates through the need to engage in activities. As time is a scarce commodity, participation in activities can be seen in terms of time allocation (Pas, 1998; Bhat and Koppelman, 1999). This implies not only that travel patterns are determined by the number and location of activities, but also, for example, that the time spent travelling cuts into the time available for other activities, thereby limiting activity demand. As far as the spatial context is concerned, the relative position of locations is thought to determine the spatial constraints. These constraints include the amount of travel needed, the feasible distances which can be covered, and even the possibility of engaging in activities (Kraan, 1998). A spatial environment with high accessibility to facilities may lead to increased involvement in activities.

Although researchers have been studying the effects of socio-demographic characteristics on activity and travel patterns, the spatial context has so far been somewhat neglected in activity research. A few studies (Pas, 1984; Ma and Goulias, 1997; Maat and Arentze, 2003) found that socio-demographics and the residential density surrounding individuals and their households significantly influence daily travel and activity patterns. Furthermore, Lu and Pas (1999) developed a structural equation model incorporating categories of in-home and out-of-home activities, travel indicators and socio-demographics, examining direct and indirect effects. They showed that travel behaviour could be better explained by including activity participation, and not by socio-demographics alone. Similar models were developed by Golob (1998), who also included car ownership endogenously and (Golob, 2000) time-budget effects. He further incorporated accessibility indices in the models, which added significant explanatory power to time use and trip generation.

In this paper we elaborate on the work of Lu and Pas (1999) and of Golob (1998; 2000). The aim of is to test whether the spatial context influences personal activity and travel behaviour. We assume the existence of complex relationships between socio-demographics, the residential context, activity participation and travel behaviour. Disentangling complex relationships requires an appropriate method of analysis. In this study, we used structural equation modelling (SEM), a technique which enables us to use a large number of endogenous and exogenous variables to identify and simultaneously estimate complex causal interrelationships. It is a particularly useful technique as it allows us to break down the causal effects into direct and indirect effects. The latter is the influence of a variable on another mediated by at least one other variable. For this analysis, we used two-day diary data.

Compared to previous research, we go a step farther by including land use as an endogenous variable. We also analyze the indirect effects of land use, participation in activities, trip generation and travel time. As the model has been developed for a non-US situation – specifically the region around Amsterdam and Utrecht in the Netherlands – it relates to a different spatial and travel setting. This is relevant since (for example) the more compact urban structure and bicycle use have their effects on travel times.

The paper is organized as follows. The next section presents the conceptual background and hypotheses. This is followed by an overview of the research methodology and data. Finally, the results are discussed and conclusions are drawn.

2. Hypotheses and the conceptual model

The primary aim of this study is to examine the influence of spatial factors on travel patterns. We begin by assuming that this is a complex process involving many indirect relationships. The structure of the model is shown in Figure 1; the premises that underpin the causal relationships are explained below in numerical order.

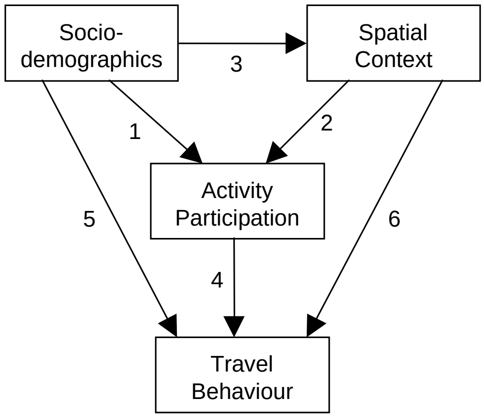

Figure 1 Conceptual model of the relationship between socio-demographics, land use and activity participation.

1. We assume first that travel results from a complex decision-making process in which people try to satisfy their preferences and needs by taking part in activities. The differences in the characteristics of individuals and households are reflected in their tastes and needs and subsequently determine the shape of their activity patterns. For example, men are assumed to spend more time than women on subsistence activities. Likewise, extra travel time needs to be generated in young families because of the need to bring and get children to and from school and sport clubs which, in turn, leaves less time for other activities.
2. Choice is also limited by the (lack of) opportunities in the spatial context; in order words, the ease of reaching destinations. The more compact the spatial configuration – because of, say, higher densities or mixed-use – the shorter the distance between home and the location of the activities and the easier it becomes to use the available amenities.
3. Third, we assume that there is a close connection between the residential environment and household characteristics. Specifically, we assume here the effect of sociodemographics on the choice for a certain residential context. For example, households with children are more likely to choose a home in a suburb and resign themselves to living farther from the urban amenities.
4. One crucially important relationship in this model is that travel stems from the wish to engage in activities. The number of out-of-home activities determines the number of trips and therefore has a strong influence on travel times and the number of trip chains. This relationship is complex because, on the other hand, time-budget relationships can also be inferred: saved travel time frees up more time for other activities which, in turn, may lead to new trips. Alternatively, the saved travel time can be used for more favoured destinations, possibly with a greater value. Both forms are referred to by the term ‘latent travel demand’. It is also assumed that activity participation is dictated

principally by subsistence activities. The amount of time spent on maintenance and discretionary activities depends on the time that is left (Golob, 2000).

5. Personal and household characteristics exercise an indirect influence on travel behaviour via activity participation. But there are also direct influences; for example, the presence of a car directly influences the amount of time it takes to reach a destination.
6. The influence of the spatial context also runs indirectly via activity participation, but a direct relationship exists as well. The more compact the built environment, the shorter the distances and the greater the savings in distance and travel time. Moreover, there is a greater chance that several destinations can be combined in a single trip chain, which also significantly cuts distance and travel time. People will be more likely to use slow forms of transport (walking, cycling) because the distances are shorter. Higher densities also offer a better support base for public transport. Finally, compactness and higher density invariably lead to lower traffic speeds and reduce opportunities for using cars. Nonetheless, time-budget effects also play a role here.

3. Methodology

Structural equation modelling makes it possible to simultaneously estimate a series of linked regression equations (Bollen, 1989; Byrne, 2001). Such a series is also known as a ‘structural’ or ‘path’ model in which a causal relationship between two variables is called a path. Variables that are assumed to be independent of any of the other variables in the model are called exogenous. As the regression equations are linked, a predictor variable in one equation can be a dependent variable in another. These are called endogenous variables. Hence, the resulting model allows the total causal effects to be broken down into direct and indirect effects. A direct effect is the unmediated influence of one variable on another while an indirect effect is mediated by at least one other variable. The total effect is the sum of the direct and indirect effects.

A specified model is usually estimated from the variance-covariance matrix using maximum likelihood estimation. In the search for the best-fitting model, the researcher tests whether assumed paths are significant. Therefore, t-values are provided for each estimated path as well as overall fit measures that indicate how well the model as a whole fits the observed data. A model’s overall ‘goodness-of-fit’ can be tested by comparing the sample variance-covariance matrix with the variance-covariance matrix that can be reconstructed from the model. The null hypothesis that both matrices are equal is tested; hence, non-significant chi-square and p values indicate that there are no significant differences between the matrices and thus that the model has not been rejected by the data. In addition, because chi-square tests are sensitive to large samples and because the assumption of perfect fit has proven to be unrealistic, other measures have been developed to indicate the overall fit (Byrne, 2001). A widely accepted measure is the adjusted goodness-of-fit index (AGFI), which basically compares the hypothesized model with no model at all (adjusted for the number of degrees of freedom). The RMSA takes into account the error of approximation and has recently been recognized as one of the most informative criteria. In addition, a closeness of fit (p-close) is provided (Byrne, 2001).

Modification indices are estimated as a means of indicating to what extent the model fit can be improved when a path that was initially assumed to be zero is freed (i.e., a coefficient is estimated for that path). In addition to the path coefficients, R2 values indicate how much of the variance of each dependent variable is explained by the variables in the model. The models in this study were estimated using Amos software (Arbuckle and Wothke, 1999).

4. Empirical context and data

4.1. Sample

The need for data about activities, travel, socio-demographics and the characteristics of the spatial context makes heavy demands on the data collection. Existing data sources, such as the Dutch Travel Behaviour Survey, neither provide activity data nor a more detailed identification of the residential location beyond the municipality. In order to obtain the required data, a new, comprehensive data set was collected based on a newly developed activity diary (Arentze *et al.*, 2001). Meantime, a range of land-use and accessibility indicators was developed from a variety of spatial data sources.

The research covered 57 neighbourhoods in a central and highly urbanized part of the Netherlands, which includes the cities of Amsterdam and Utrecht and some smaller towns, suburbs and villages. The neighbourhoods were chosen carefully such as to encompass a wide variety of urban forms (see also Maat and Arentze, 2003). The survey was conducted in the spring and autumn of 2000. It was preceded by a random sample of 50,000 questionnaires to select households that were willing to participate. A total of 3,300 questionnaires were sent to those who were filling to participate in the study. To prevent over- and under-representation, the proportion of respondents over the age of 50 was reduced while the proportion of public transport users was increased. A total of 3,412 individual questionnaires and diaries, covering 1,960 households, were returned. However, the actual sample used for analysis was further reduced because of missing values and the need for diary entries relating to two full weekdays (weekend days are not comparable with working days). Furthermore, only persons over the age of 18 were selected. This resulted in a sample of 1,852 individuals.

The main survey involved a questionnaire with a list of questions related to the household and residential context plus a personal questionnaire focusing on demographic and socio-economic characteristics, a personal questionnaire about customary activity patterns (not used in this paper), and an activity-travel diary. All the respondents were asked to record their activities and trips in the diary for two consecutive days, with the pairs of days staggered across the seven days of the week.

The spatial data were derived from a variety of sources and pre-processed with the aid of a GIS. Dwellings were obtained from the LBV National Database of Real Estate (1999), and the number of employed persons from the LISA Register of Businesses (1999). The Basic Register of Points-of-Sale (1999) contains detailed information on shops, including the amount of floor space devoted to sales, broken down for daily shopping and non-daily shopping. The data were assigned to their locational position with the aid of postal codes, which provide highly detailed spatial information. Distances and travel times between origins and destinations were calculated using the Basis Network (2000).

4.2. Activity and travel variables

All the behavioural variables were measured and applied for two days. Activity participation was expressed as the number of minutes spent on activities. The activities were classified according to three out-of-home categories: subsistence (work, education), maintenance (e.g. shopping, visits to services such as the doctor, bank, post-office, library and get/bring activities) and discretionary (e.g. leisure, social visits, sport). There was also an in-home category (working at home, study and housekeeping).

Travel behaviour was split into four variables: number of trips, number of tours, travel times and travel distance. Tours are trip chains that start and end at home. Walking the dog is a typical example of a tour without an interim destination. Complex tours cover more destinations, such as work and shops. Travel distance was measured across the road network using geographical information system. The average time taken for each category of activity and the averages of the travel variables are shown in Table 1.

Table 1 Descriptive statistics of the activity participation and travel variables over two days

		For cases > 0	
	Percent cases > 0	Mean	SD
Duration at home [hour]	90.5	5.02	4.14
Duration subsistance [hour]	79.7	12.35	5.72
Duration maintenance [hour]	78.5	1.14	1.08
Duration discretionary [hour]	67.6	3.92	4.04
Number of trips	100	9.26	4.57
Travel time [hour]	100	3.19	1.75
Travel distance [km]	99.5	110.54	92.92

N= 1852

4.3. Personal and household variables

The socio-demographic variables correspond with the ones used in similar studies, namely: age, gender, personal income, the presence of children in the household, the availability of a car and the availability of discount tickets for public transport. Income was measured on a 9-point scale. Two dummies indicated the presence of children in the household, namely children under the age of 6 and children aged between 6 and 12. Car ownership was measured as the individual availability of a car: this was more easily explainable in the models than the number of cars per household or the possession of driver's license. Public transport discounts related to the bus, tram, metro or train. The availability of a bike was not included because of the high number of missing values. Table 2 provides some descriptive statistics.

4.4. Land-use variables

To reflect the characteristics of the built environment, we followed the assumptions of land-use concepts that assign an important role to density and mixed-use. As such measurements are sensitive to differences in shape and size, administrative and statistical divisions (e.g. neighbourhoods or postcode areas) proved inadequate. This problem was addressed by converting the data into grid cells measuring 750 by 750 metres. In order to take account of the gradual transitions between the grid cells, we started with 250-metre cells, and aggregated them to 750 metres by calculating the spatially moving average for each cell (the average value of the cell itself as well as the values of the eight adjoining cells). This way we created figures of areas of 750 by 750 metres, depicted in 250-metre increments. The data on urban land use were converted into several indicators (Table 2).

Density was measured in single-use indicators, namely the number of houses, jobs, and shopping floor space, as well as the proportion of multi-storey dwellings. Furthermore, a density index was developed, which used one figure for each cell to express the total density of housing, employment, and shopping. Since these categories are measured in units that are not comparable, the variables were standardized with the national totals (Maat and Harts, 2001).

The entrophy index (Eq. 1) (*cf*. Kockelman, 1996) was used as a measure of land-use mix of housing, employment and shopping. As in the density index, standardized values were used. $Entrophy_i = -\sum_j \frac{P_j \times \ln(P_j)}{\ln(J)}$ where Pj denotes the proportion of land use j in cell i. In order to obtain a value between 0 and 1 (with 1 indicating the perfect mix), the measure was normalized with respect to the natural logarithm of the number of uses.

Table 2. Descriptive statistics of the personal, household and land use variables

Exogenous variable		N	Mean	SD
Personal and household				
Age			44.5	12.8
Gender	female	940		
	male	912		
Presence of children below 6 yr of age		374		
Presence of children 6 -12 yr of age		240		
Car available		1475		
Publ Transport fare reduction		722		
Income	no income	130		
	< 10.000	101		
	10.000 - 20.000	121		
	20.000 - 30.000	191		
	30.000 - 40.000	271		
	40.000 - 50.000	253		
	50.000 - 60.000	253		
	60.000 - 70.000	152		
	> 70.000	380		
Land Use				
Density Index (0-100)			10.0	6.3
Entrophy Index (0-1)			0.43	0.24

N = 1852

5. Empirical results

5.1. Model fit

In order to find a good model fit the model was estimated in two phases. The initial model specification was based on the conceptual model described in Section 2. The personal and household characteristics were specified as exogenous variables and the activity durations (number of trips and total travel time) were specified as endogenous variables. Two land-use variables were specified: density and entropy. The following causal paths were estimated: (1) from all socio-demographic to all endogenous variables, (2) from the land-use variables to the activity durations and the travel variables, (3) from subsistence duration to home, maintenance and discretionary duration, (4) from all activity durations to both travel variables and (5) from number of trips to travel time.

We then tested how good the data fitted the initial model. The chi-square value was 228.435 with 31 degrees of freedom, resulting in a p value of 0.000. Hence, the model did not describe the data well and needed to be improved. It was revised as follows: all non-significant paths and correlations were fixed to zero; the land-use variable entropy was removed because it turned out to have no effect on the activity duration; paths and correlations that were not included in the model (i.e. were fixed to zero) were added insofar as the modification indices suggested that they would significantly improve the model and insofar as this was considered theoretically plausible. It is, for example, considered implausible in our conceptual model that an increase in discretionary activities would result in less subsistence; we assume that (for the greater part) people use the remaining time from compulsory activities for discretionary activities.

The overall fit of the final model was good, producing a chi-square of 40.818 with 31 degrees of freedom, resulting in a p value of 0.112. Thus, the model could not be rejected at the 5% probability level. This was confirmed by an AGFI = .99 (values > .90 indicate good fit), an RMSA = .013 (values of less than .05 are good) and a p-close = 1.000.

The explained variances of the endogenous variables are listed in Table 3. The model seems to provide a reasonable explanation of the duration of subsistence and at-home activities. Maintenance and discretionary activities however, are largely unexplained, as may be concluded from the strong correlation between the unexplained portions. Both travel variables are reasonably explained. The influence of personal and household characteristics on density appears to be small.

Table 3. Proportion explained variance of the endogenous variables

Endogenous variable	R-square
Sqrt Density	0.07
Duration subsistance	0.36
Duration at home	0.45
Duration discretionary	0.06
Duration maintenance	0.24
No. of trips	0.29
Sqrt total travel time	0.29

5.2. Relationships between activities and travel

The estimated direct, indirect and total effects are shown in Table 4. The analysis of the relationship between the activities themselves confirmed the hypothesis that the duration of the subsistence activity was the driving force behind the other categories of activity (*cf.* Golob, 2000). The more time people spend on subsistence, the less time they have for other things. There is also a negative correlation between the other out-of-home activities and in-home activities.

The theory that travel stems from participation in activity is confirmed. The more time people spend on maintenance and discretionary activities, the greater the number of trips. Though the duration of subsistence has no direct effect on trip generation, it does have an indirect effect: people who work a lot have less time for out-of-home activities and therefore make fewer trips. Daily travel time is derived mainly from the number of trips: people who make more trips travel longer. In addition, it appears from the indirect effects that the duration of out-of-home activities increases travel times. The same conclusions can be drawn in a model in which travel time is replaced by travel distance; however, the effects are then slightly weaker. It can therefore be concluded that people align their behaviour more with time than with distance.

5.3. Effects of personal and household variables

As was expected, personal and household characteristics affect participation in activities. For instance, men spend less time on maintenance activities. There is also a strong positive link between subsistence and income and a strong negative link between subsistence and age. One effect which is both direct and indirect is the decline in the duration of maintenance in relation to a rising income; here the indirect influence is exercised through the duration of subsistence.

Trip generation is primarily dictated by activity participation, but socio-demographics are also responsible for some direct effects, the most striking being that people with children in both age groups make more trips without extending the duration of activity: get and bring tasks are the most obvious explanation for this. Travel time is also influenced by socio-demographics. Higher-income groups make longer trips; this effect comes on top of the effect of longer duration of subsistence. People with a discount ticket for public transport also spend a bit more time travelling.

5.4. Effects of land-use variables

Initially, we tried to include more land-use variables in the model. We experimented with various densities, the entropy index for mixed-use and proportion of multi-storey dwellings. Eventually, we found that a model could be compiled with only two measures: the composite density index and the entropy index. It transpired, however, that in this model entropy had no effect on any of the endogenous variables. Models with density and (to a lesser degree) entropy proved individually to have good fit; up to now only the model with density has been described.

The explained variance of density as an independent variable is low (only 7 percent). Even so, the effects of socio-demographics are plausible. In particular, the availability of a car is negatively related to density, while a discount ticket for public transport is positively related to density. People with children in both age groups (and higher) tend to opt for lower-density areas. Interestingly, the preference for higher density increases with income.

The influence of density as a predictor of activities and travel is plausible to some extent. As density increases more time is spent on maintenance and discretionary activities. This can be explained by the fact that higher densities go hand in hand with amenities. It also has a positive direct influence on the number of trips and an indirect positive influence through the activities. Though one might expect density to have a direct reductive effect on travel time, this is not the case. Nonetheless, travel time does increase as a result of the indirect effect of the extra trips in high-density neighbourhoods.

6. Conclusions

In recent years many studies have addressed the relationship between land use and travel behaviour. At the same time, the notion that travel demand stems from activity demand has been explicitly incorporated into activity-based models. The role of spatial context in the activity-based approach has, however, been largely neglected. This paper has explored the influence of spatial variables on personal activity and travel behaviour, controlled for personal and household variables. For this purpose a structural equation model was developed to simultaneously estimate direct and indirect causal relationships. The model was based on two-day diary data that was collected in the region of Amsterdam and Utrecht.

The model fit was good, as was the explained variance between the activity and the travel variables. Relationships between socio-demographics, land use, activity and travel could be estimated simultaneously. Significant relationships emerged between the activities themselves and with trip generation and travel time demand. The diverse socio-demographics also clearly exercised a direct and indirect influence on the endogenous variables. The spatial variables, however, (the density and entropy index) exercised only a weak but nonetheless significant influence on the activity and travel variables. One (tentative) conclusion is that indirect effects can steer a total effect in another direction. For example, though density has no direct effect on travel time, the total daily travel time still increases because of the extra trips in high-density areas. From a policy perspective, this effect of density on travel behaviour would mean that aiming at higher densities runs counter to the aim of reducing travel kilometres.

Future research could concentrate on including more spatial and accessibility variables. It could also explore whether extra travel indicators, such as the number of trip chains and variables relating to the modal split, could be added to the model.

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Table 4. Estimated direct, indirect and total effects *

Explanatory variables	Exogeneous							Endogenous					
Endogenous variables	Gender	Age	Income	Children 6-12 yr of age	Children below 6 yr of age	Car available	Reduced fare	Density (sq.)	Duration at home	Duration subsis-tance	Duration mainte-nance	Duration discre-tionary	Number of trips
Direct effects													
Density (sq.)	-0.07	-0.07	0.12	-0.09	-0.06	-0.10	0.17						
Duration at home	-0.13			0.16	0.24		-0.06	0.06		-0.60	-0.08	-0.24	
Duration subsistance	0.10	-0.44	0.43		-0.09			-0.04					
Duration maintenance	-0.12		-0.06	0.04	0.11	0.06				-0.40			
Duration discretionary		-0.12	0.09	-0.07	-0.12			0.06		-0.26			
Number of trips		-0.05	-0.06	0.19	0.18	0.10		0.04			0.40	0.19	
Total travel time (sqrt.)			0.19				0.07		-0.18	0.14		0.19	0.37
Indirect effects													
Density (sq.)													
Duration at home	-0.05	0.25	-0.23	0.01	0.06	-0.01	0.01	0.01		0.09			
Duration subsistance							-0.01						
Duration maintenance	-0.04	0.17	-0.17		0.03			0.02					
Duration discretionary	-0.03	0.11	-0.10	-0.01	0.02	-0.01	0.01	0.01					
Number of trips	-0.07	0.06	-0.09		0.04	0.02	0.01	0.02		-0.21			
Total travel time (sqrt.)	0.01	-0.10	0.04	0.02	-0.01	0.04	0.01	0.02		-0.03	0.16	0.11	
Total effects													
Density (sq.)	-0.07	-0.07	0.12	-0.09	-0.06	-0.10	0.17						
Duration at home	-0.18	0.25	-0.23	0.17	0.31	-0.01	-0.05	0.07		-0.51	-0.08	-0.24	
Duration subsistance	0.11	-0.44	0.43		-0.09		-0.01	-0.04					
Duration maintenance	-0.16	0.17	-0.23	0.04	0.15	0.05		0.02		-0.40			
Duration discretionary	-0.03	-0.01	-0.01	-0.08	-0.10	-0.01	0.01	0.07		-0.26			
Number of trips	-0.07	0.02	-0.15	0.19	0.21	0.11	0.01	0.06		-0.21	0.40	0.19	
Total travel time (sqrt.)	0.01	-0.10	0.24	0.02	-0.01	0.04	0.08	0.02	-0.18	0.11	0.16	0.30	0.37

* All reported effects are significant at the $p = 0.05$ level

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