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Incorporating time dynamics in activity-travel behaviour model: A path analysis of changes in activity and travel time allocation in response to life cycle events

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ABSTRACT

The study of dynamics in activity and travel behavior is not a new research interest in transportation field. There are a few arenas in the dynamics which have been partially covered, yet some remain rather unexplored. Short term dynamics of activity and travel behavior are better understood than long term changes in the contemporary research. For instance, intra-household decision making, day-to-day dynamics of activity-travel generation and scheduling, out-of-home or in-home activity organization have been addressed by a number of studies. However, one can rarely find studies on the dynamics of time allocation in activities and travel related to life cycle events. This study contributes to the understanding of such long term dynamics. Using path analysis it shows the effect of several life cycle events on the changes in time allocation in activities and associated travel. Data were collected in the Netherlands in September 2011 using an event-based questionnaire survey, where the respondents were asked to report a weekly activity and travel schedule before and after the event. Results also show the interdependencies between the types of activity and travel. We conclude that life cycle events have significant impact on changes in time allocation for activities and travel. The effects are varied in direction, intensity and existence according to the type of event and the type of activity. The findings contribute to the specification of dynamics in activity-travel time allocation and predicting the rapid and far reaching changes in addition to the day-to-day dynamics.

Keywords: Activity travel dynamics, Dynamics in time allocation, Life-Cycle events, Structural Equation Modelling, Path Analysis.

1. INTRODUCTION

In the activity-based research community, it is generally accepted that travel is derived from the organization of daily life in time and space. Individuals and households participate in activities, often at locations other than home. In turn, activity participation reflects underlying needs for productive and reproductive time use. People need to work, wish to relax, need to replenish their food supply, desire to interact with other people, etc. With time these needs change and so does the activity allocation. In an attempt to forecast activity and travel demand, transportation research has focused on modeling these dynamics in the short term, mid-term and long term. The short term dynamics are more concerned with within day and day-to-day activity-travel behavior. Contemporary research has covered almost all aspects of activity and travel (mode choice, timing, sequence, duration and activity-travel party) and has shown that they are mostly dependent on household characteristics and available mobility choices (*1-4*). There are a number of advanced and operational models to predict short term dynamics of activity-travel behavior (*5, 6*)

In the long term, dynamics life-cycle events have been considered as an important trigger of change in activity-travel patterns. Particular life trajectory events such as marriage, birth of a child, job change or residential move may bring the system out of balance, increase stress, and prompt travelers to reconsider their travel options. Life trajectory events may therefore lead to changes in activity-travel schedules and patterns (*7, 8*). These dynamics may apply to all activities and all aspects of travel behavior. However, only a few aspects have been explored so far, such as mode choice(*9*), car ownership(*10, 11*), commute distance(*12*) and travel time(*13*). There are also studies focusing on one particular event and the effects on travel behavior, such as residential relocation (*14*) and childbirth (*15*). However, to the best of our knowledge, no studies have looked at the long term dynamics of time allocation for different activities and associated travel. There is also limited research incorporating a range of life cycle events to see the combined dynamics. We stress that it is important to incorporate a number of key events so as to get a comprehensive image of the type and level of impacts caused by different types of life-trajectory events. The study contributes to this end.

Life-cycle events are frequently used as a key trigger to analyze mobility decisions in the long term and are widely accepted. We apply the same approach here. Five lifecycle events (viz. residential relocation, getting married/divorced/cohabitation, children starting school, starting new job and starting University) have been used here to analyze the dynamics in activity and travel time allocation before and after the event. Structural equation modeling has been used to establish the relationships.

The paper contains five more sections. Section two discusses the existing literature in the topic. Section three contains the conceptual framework. Section four explains the data and methodology used in the paper. Section five includes a detailed discussion on the results and the last section summarizes the findings in the concluding remarks.

2. LITERATURE REVIEW

A number of studies have investigated different aspects of activity and travel behavior dynamics and life-cycle events. Most of the studies are focused on one of the travel behavior indicators with one of the life-cycle events. Some have incorporated several life-cycle events with one of the travel behavior components. Since the objective of the paper is associated with two key concepts, namely, life-cycle event and activity-travel dynamics, here we will focus on literatures on the association of those only.

Literature on long-term dynamics of activity-travel behavior can be broadly divided into two parts: studies investigating mode choice or car ownership changes with one or several life-cycle events and studies analyzing travel (commute) time changes with one or several life-cycle events. Brief discussion on those follows here.

2.1 Life-Cycle Events and Mode Choice Dynamics

One of the earliest work on life-cycle events was by Lanzendorf (*16*). He extended the theory of Salomon and Ben-Akiva (*17*) and proposed a mobility biography approach, which says that travel behavior are habitual and define three hierarchical domains: a lifestyle domain, an accessibility domain and a mobility domain, within which the interactions occur and travel behavior is evaluated. Based on the concept Prillwitz et al (*11*) explain changes in car ownership by changes in life course stages. They show that key life-cycle events have a strong impact on car ownership growth.

A related study was conducted by Waerden et al (*9*). They report that critical incidents (such as accidents) and life-cycle events bring disequilibrium in activity travel repertoires. Such incidents change individual's mode choice and available options. Following that, Verhoeven et al (*7*) report effects of life trajectory events on mode choice behavior using Bayesian Belief Networks. They also confirm that events have an influence in leading to structural decision about mode choice. The study was based on retrospective survey among 710 respondents in 2004.

A more recent study is conducted by Oakil et al (*10*). Using a retrospective survey data collected in 2010 in the Netherlands, they developed a mixed logit model with an assumption that life-cycle events have a lag and lead effect. Their findings suggest that an increase in car ownership is associated with residential relocation and (anticipated) child-birth event and a decrease in car ownership is associated with divorce and change in job.

2.2 Life-Cycle Events and Commute Time Changes

There are only a few studies investigating the association of life-cycle events with travel time dynamics. Mostly commute time changes are Similar to the car ownership study Prillwitz et al (*12*) used mobility biographies to study the influence of key lifecycle events, with a focus on residential relocation and commute distance. Using the German socio-economic panel data they ran descriptive analyses and linear regression models. They used commute distance as an indicator of travel behavior and concluded that events like marriage and birth of child do not play a significant role in terms of commute distance changes. However, residential relocation has an influence. Commute distance increases when people move from a regional core to a non-core area.

Clark et al (*18*) investigated the effect of residential relocation and job location on commute distance using the Puget Sound Transportation Panel. The results support rational behavior of people as they choose to move at places closer to the work location, hence decreasing commuting distance. They also note that women commute less than men. Using the same panel data Chen and Chen (*19*) show that built environment affects the response lag of a significant increase . Moreover their result show that, an increase in the income will result in a longer response lag while an increase in the number of vehicles and the household size will result in a shorter response lag in time allocation for discretionary activities.

However the understanding of the long-term dynamics of joined activity and travel time allocation and their interdependencies has largely been overlooked in the empirical studies. To

that end, the paper developed a structural model to explain how activity and travel time allocation change with life cycle events.

3. CONCEPTUAL FRAMEWORK

The conceptual framework proceeds with one basic assumption that life-cycle events bring the daily activity-travel schedule out of balance and introduce the need for rescheduling and reallocating time for activities and travel. Since the total time budget is fixed we hypothesize that distribution of daily time is allocated on a priority basis. Time is first allocated for subsistence activities, then to maintenance activities and the remaining to leisure activities. Activities are divided into three broad categories and we define them as follows:

1. Subsistence activities: Work, study
2. Maintenance activities: Daily grocery shopping, picking up/dropping off people/goods, visit to pharmacy, barber shop, post office, dry cleaning, etc.
3. Leisure activities: All other activities

The concept is displayed in Figure 1. The elements in the box represent the activity travel behavior at a specific point of time or life stage.

However, when an important life-cycle event occurs, this whole scheduling process may need to be re-shuffled. In this regard, we categorize the events as well which may have an impact on particular sets of activities. Not all life-cycle events should influence all types of activity and travel. The level and intensity of the effect on the time allocation should differ as well. Henceforth, we hypothesize that:

H1: Events with direct components related to subsistence activities (such as, starting new job or education) directly affect time allocation on subsistence activities.

H2: Events with components related to the entire household (such as, moving house, children starting school) directly affect the time allocation between subsistence and maintenance activities.

H3: Events with high potential influence on personal social networks (such as getting married/cohabitation) directly affect the time allocation in maintenance and leisure activities.

4. DATA AND METHODOLOGY

A Web-based questionnaire survey was carried out in September 2011 in the Netherlands among a random sample of the population to collect the data. A criterion used to select respondents was that they must have experienced one of the life cycle events (which were residential relocation, getting married/divorced/cohabitation, children starting school, starting new job and starting University) within the past two years. If multiple events have been experienced then the respondent would choose the most recent one to answer the questions. If they satisfied this criterion, respondents were forwarded to a set of questions related to the event. The questionnaire was divided into four parts Part one was about their present socio-demographics, part two about social network, part three about their weekly activity and travel schedule and part four about memberships to clubs and social organizations. In this study, we analyze part of the data collected in part three of the questionnaire.

The (translated) phrasing of the question was as follows:

‘In the next question we want to know about your activities and travel before and after the (specified) event. Please mention which activities you perform and how you travel in a typical week. Think of your last regular (non-holiday) week when you answer the

following questions. Some activities you might do on weekends (e.g. visiting friends / relatives, outdoor recreation). Please mention them as well. If an activity or trip is not applicable to you then please select "not applicable." for that specific activity/trip.'

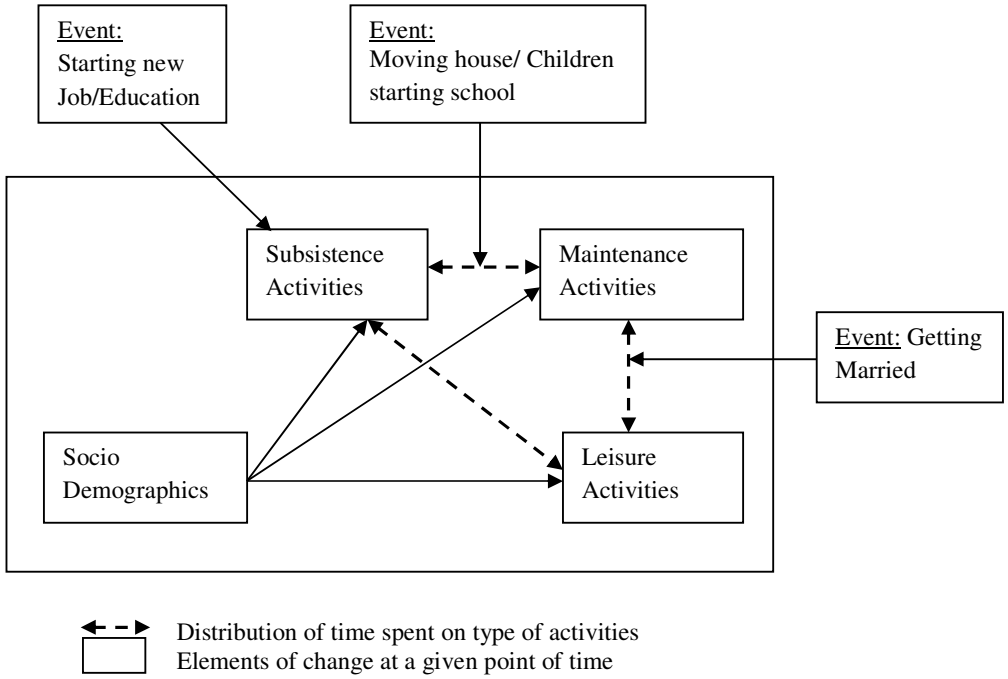


FIGURE 1 Conceptual framework of dynamic distribution of time spent on activities

The respondents then had to fill out a table. In the rows, there were the activities and in the columns were the details of the activities (number of activity per week, average activity duration, company of activity, travel mode and average travel time per mode). For each activity two rows were assigned: one for the before the event and one for after the event (present day). If nothing has changed for an activity then they were asked to keep the latter row for each activity blank.

In this study we focus on the changes in activity and travel time allocation for the activity categories mentioned in section two. We calculated the changes in activity time before and after the event. To calculate travel time, we multiplied trip duration per mode with the number of times that the mode was used per week for that specific activity. If multiple modes were used, we added all the travel times together to obtain the total travel time for one specific activity per week. Then, we calculated changes in travel time before and after the event for each specific activity. Finally, we consolidated the activity types according to the categories mentioned in section two. Here, we consider only out-of-home activities and the unit is hours per week. Table 1 represents the characteristics of the sample (632 cases) used in the study. Respondents also gave an estimate of the size of their present social network which was included in the study as an endogenous variable.

TABLE 1 Sample Characteristics (mean of 632 cases)

Variable	Definition	Type	Unit	Value
Exogenous Variables				
Socio-Demographics				
Age	Age (years)	Continuous	n	34.74
Male	Gender (male)	Categorical 1 if true, 0 if not	%	53.1
#HHmember	Number of household member	Continuous	n	3.21
#child	Number of child in the household	Continuous	n	1.04
Working	Working (yes)	Categorical 1 if true, 0 if not	%	67.2
Studying	Studying (yes)	Categorical 1 if true, 0 if not	%	18.8
Driving License	Driving License (yes)	Categorical 1 if true, 0 if not	%	78.5
#car	Number of cars	Continuous	n	1.04
Have car always	Car available always (yes)	Categorical 1 if true, 0 if not	%	57.2
Life-Cycle Events				
Event: New Job	Event: Starting new job	Categorical 1 if true, 0 if not	%	23.4
Event: Start University	Event: Starting University	Categorical 1 if true, 0 if not	%	11
Event: Child Starts School	Event: Children starting school	Categorical 1 if true, 0 if not	%	23.8
Event: Relocation	Event: Residential relocation	Categorical 1 if true, 0 if not	%	20.8
Event: Wedding	Event: Getting married/separated/divorced/cohabitation	Categorical 1 if true, 0 if not	%	21
Endogenous variables				
Social Network Size	Size of social network	Continuous	n	28.53
Activity-Travel time allocation variables (dynamics)				
AT: Subsistence	Change in subsistence activity time (AT)	Continuous	n	0.399
AT: Maintenance	Change in maintenance activity time (AT)	Continuous	n	0.357
AT: Leisure	Change in leisure activity time (AT)	Continuous	n	0.476
TT: Subsistence	Change in subsistence travel time (TT)	Continuous	n	1.460
TT: Maintenance	Change in maintenance travel time (TT)	Continuous	n	1.420
TT: Leisure	Change in leisure travel time (TT)	Continuous	n	1.484

The objective of this study is to explore the relationships between socio-demographics and life-cycle events with the dynamics in time allocation of activity and travel and the size of the social network. The second set of variables is endogenous (changes in activity-travel time allocation and social network size) and assumed to have some sort of interdependencies among each other. Please note that while the activity-travel variables were calculated as changes, social-network size was presented as a static variable and represents present social network (i.e. after the event). It should also be noted that since the activity and travel times are adopted as (positive or negative) changes relative to the before-event situation, the effects of independent variables which we estimate in this framework should be interpreted as effects on a response to the event.

Structural Equation Modeling is a powerful technique to effectively handle these relationships as it can effectively capture the causal influences of the exogenous variables on the endogenous variables and the endogenous variables on each other (*20*). Since all of them are observed variables, we developed a structural model (path analysis).

5. ANALYSIS AND RESULTS

The results of path analysis using LISREL are discussed in this section. The objective was to examine the relationships between changes in activity and travel time allocation (for subsistence, maintenance and leisure activities before and after event) with type of event and socio-demographic characteristics. We followed the network structure as mentioned in the conceptual framework. Based on the modification indices we modified the final model and removed those relationships that were not significant on a 0.1 significance level. Figure 2 shows the structure of the final model. Since the activity categories are endogenous, we also look into their interdependencies. Table 2 presents the results. The interpretation of the results is organized in four sub-sections below. At first the influence of exogenous variables on endogenous variables (Figure 2) is described followed by a discussion on the effect of endogenous variables on each other (Figure 3).

A number of measures are employed to assess the goodness-of-fit in SEM. One is the Akaike Information Criteria (AIC) which compares the Maximum Likelihood estimation goodness-of-fit and the parsimony of the model (*21*). A good fit is when the model AIC and saturated AIC are close to each other. Another is that the Normed Fit Index (NFI) should be close to 1. Another indicator is the value of Chi-square divided by the degree of freedom which should be less than 2. Also the Root Mean Square Error of Approximation (RMSEA) should be less than 0.05 (*20, 22*). The goodness-of-fit measures are presented in table 3 and according to them the model is acceptable. The reduced R-squares show that the explanatory power of the exogenous variables is modest.

5.1 Socio Demographics and Activity-Travel Dynamics

At first let us discuss about the effect of socio-demographic characteristics with changes in activity and travel time allocation. We observe that age has a positive association with changes in leisure activities (both activity time and leisure time). With growing age the time spent on leisure activities in response to an event increases.

Professions like working and studying have a positive effect on changes in both activity and travel times for subsistence activities.

Number of household members has a positive effect on changes in leisure activity time whereas the effect on changes in leisure travel time is negative. On the contrary number of children has a negative effect on change in leisure activity time and a positive effect on change in leisure travel time. Change in time spent on leisure activities decreases for households with more children whereas change in the time spent on leisure travel increases. Perhaps households with children after the event go on longer leisure trips and reduce the activity time spent on leisure to compensate for this. Interesting effects can be seen in the activity and travel (commute) time changes for subsistence activities with number of children in the household. People with more children tend to work and commute less in response to the event.

Change in leisure travel time also decreases with all the transport mode availability (driving license, having car always available and the number of cars in the household) variables. Variables like, households with more car, people with driving license and car always available

have negative influence on changes in leisure travel and activity time. Only a positive effect is seen with possession of driving license and leisure activity time. Moreover car availability (always) has a positive association with time spent on subsistence activities after the event. On the other hand change in subsistence activity time is influenced negatively by number of cars available in the household. Moreover availability of car (always) has a negative effect on change in maintenance activity time but a positive effect on change in maintenance travel time. Opposite effect can be observed for the number of cars in the household.

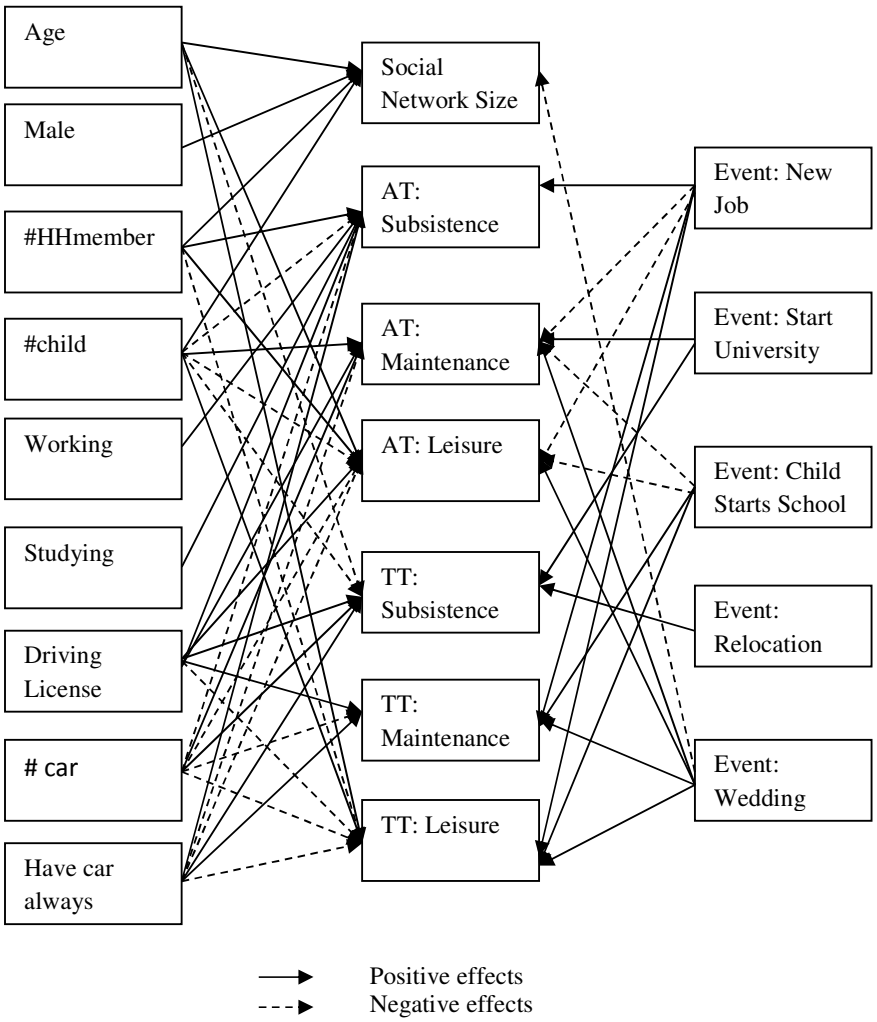


FIGURE 2 Effects of exogenous variables on endogenous variables

5.2 Social Network Size

The size of personal social network was included in the study as an endogenous variable also depending on socio-demographics and life cycle events. We observe that age has a positive association with the size of social network. We should note that the social network size variable is not a 'change' but rather a 'static' one. Number of household members and number of children in the household both have a positive effect on the size of social network.

Interestingly, the event of getting married/divorced/separated/cohabitation has a negative effect on the size of social network after the event. Other types of event do not have an impact on social network size.

The size of social network has a positive influence on the change in leisure activity time, which is somewhat expected. It also has a positive impact on change in travel time for maintenance activities. However, it has a negative impact on change of activity time for maintenance activities.

TABLE 2 Results from Path Analysis of Time Allocation Dynamics of Activities and Associated Travel

	Change in Activity Time (AT)			Change in Travel Time (TT)			Social Network Size
	Subsistence	Maintenance	Leisure	Subsistence	Maintenance	Leisure	
Age			0.01	-2.17		0.03	0.03
Male							4.42
Working	0.14						
Studying	1.12						
#HHmember	0.94		2.10			-1.19	0.45
#child	-0.83	0.13	-1.42	-1.81		4.06	2.02
Driving License	0.5	0.66	0.36	0.57	0.06	-1.16	
Have car always	0.02	-1.09	-0.27	0.61	0.16	-3.37	
#car	-0.2	0.07	-2.77	0.57	-0.18	-3.43	
Event: New Job	0.44	-0.66	-1.03		0.24	1.72	
Event: Start University	1.74			2.53			
Event: Child Starts School		-0.77	-1.21		0.12	1.51	
Event: Relocation				-0.55			
Event: Wedding		0.77	1.15		0.34	2.18	-8.96
AT:Subsistence		0.24	0.19				
AT:Maintenance	-0.17			0.17			
AT:Leisure		1.96				0.06	
TT:Subsistence	0.11						
TT:Maintenance	0.02			0.05			
TT:Leisure	-0.92		0.04	-0.08	3.69		
Social Network Size		-0.09	0.1		0.41		
R^2	0.05	0.01	0.35	0.05	0.03	0.30	0.01
R^2 reduced form	0.05	0.01	0.30	0.03	0.03	0.30	0.01

TABLE 3 Goodness-of-fit Statistics of the Model

Goodness of Fit Statistics
Degrees of Freedom = 47
Minimum Fit Function Chi-Square = 49.16 (P = 0.39)
Chi Square/Degree of Freedom = 1.04595
Root Mean Square Error of Approximation (RMSEA) = 0.0084
90 Percent Confidence Interval for RMSEA = (0.0 ; 0.028)
Model AIC = 459.04
Saturated AIC = 462.00
Normed Fit Index (NFI) = 0.99

5.3 Type of Life-cycle Events and Activity Travel Dynamics

Type of event has varied and significant impacts on time allocation dynamics of activity and associated travel. The impacts are consistent and logical. Getting a new job increases subsistence activity time and reduces maintenance and leisure activity time. However, travel time for leisure and maintenance activities increases. Starting at the University for higher education increases both activity and travel time for subsistence activities. The travel time increase can be explained by the fact that Netherlands is a small country with practically free public transport for students. Therefore they can still live with parents and commuting to attend the university is a common practice among the young population (*23, 24*). Hence, hypothesis one (H1) is consistent with the results that events associated with subsistence activities would affect time allocation on subsistence activity and travel. In addition, we observe some effects on leisure and maintenance activities.

The event of children of the household starting school reduces time spent on leisure and maintenance activities. Similar to the effect of number of children variable, it is observed that travel time to leisure activities increases. This might also incorporate the seasonal effect of leisure travel. In general, in Netherlands (and most of the European countries) households with children enjoy long holidays and leisure activities during summer vacation of schools. They plan their holidays of the year around the summer months. The data here represents activities in a typical week before and after the event and was collected in September. The results show that residential relocation decreases travel time for subsistence activity. This can be explained by the fact that most of time people relocate to places closer to their work places to reduce commute time(*18*). The event does not have significant effect on other activity travel dynamics. Thus, the second hypothesis (H2) is reasonably consistent, which was that events related to big changes for the entire household will affect the time allocation between subsistence and maintenance activities. Likewise to hypothesis two, we find effects on leisure activity and travel time allocation as well.

The event starting cohabitation or getting married/separated/divorced increases both activity and travel time for leisure and maintenance activities. This is in support of hypothesis three (H3) that events with potential significant impact on social network affects maintenance and leisure activity (and travel) time allocation, perhaps because people go on leisure trips and social events more after they got married or started cohabitation and also the new household may have new maintenance activities. Empirical evidence shows that newly married couples without responsibility of children spend more than 5 hours per week on out-of-home recreation, which is higher than the other family life cycles, except bachelors(*25*). Maintenance activities may increase after separation or divorce since the partner is no longer around to help out. Moreover they might also have more time budget on hand. The event has no significant effect on subsistence activity dynamics, which is expected.

5.4 Interdependencies Between Activity and Travel Dynamics

In this section, we will discuss activity and travel interdependencies among the activity categories (Figure 3). We hypothesized that people prioritize subsistence activities first, maintenance activities second (if any) and leisure activities and schedule them accordingly. So if there is any change in time budget, first they would allocate for subsistence activities and then maintenance and leisure activities respectively. The hypothesis is based on the flexibilities associated with each type of activity. This would imply a one way link from subsistence activity

to other activity categories. However, the results do not necessarily confirm the activity priority hypothesis. We see some evidence of a two way link between the categories.

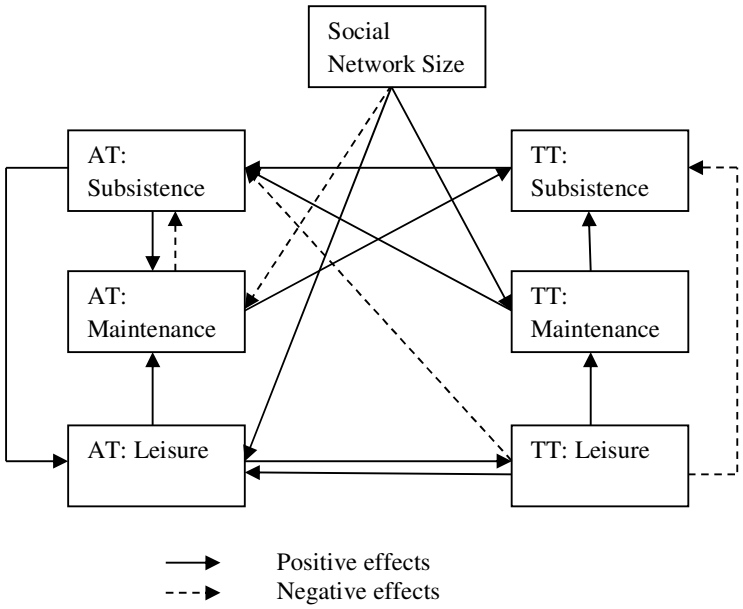
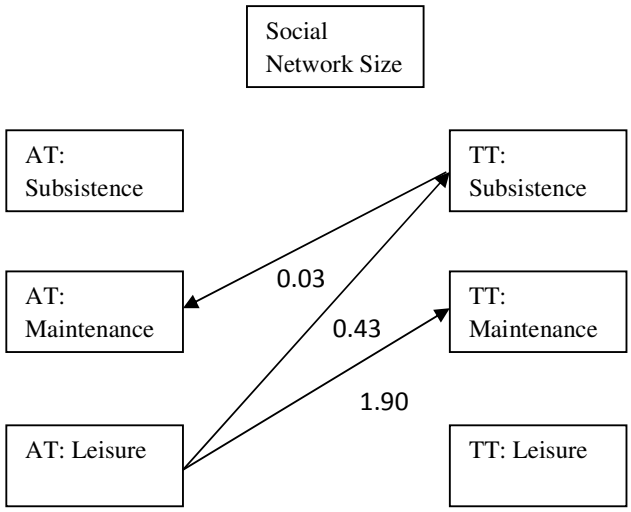


FIGURE 3 Interdependencies among endogenous variables (direct effects)



Only significant (p>.05) effects are reported

FIGURE 4 Interdependencies among endogenous variables (indirect effects)

The results show that an increase in subsistence activity time relates to an increase in time allocation in maintenance and leisure activities. This may directly be associated with income. More subsistence activity (work, or study and work for students) could mean more income and thus, more budget for maintenance and leisure activities. On the other hand, an increase in maintenance activity causes a decrease in activity time and an increase in travel time for subsistence activities. Since some maintenance activities are done on the way to and from work (such as picking up, dropping off children) increase in maintenance activities could increase travel time to work, which may also mean less working hour (subsistence activity time). Moreover, we have seen from the effect of socio-demographics that more children in the household (and hence more maintenance activity) means that people start working less after the event.

For leisure activities, the relation goes from leisure to maintenance activity. An increase in leisure activity leads to an increase in maintenance activity.

In terms of interdependencies between activity time and travel time we observe a mutual effect for subsistence and leisure activities. So any change in travel time for any activity is associated with a positive effect in the activity time for the activity and vice versa. Levinson (*26*) found relations on the other direction that activity duration has a strong positive effect on travel duration. However, the variables did not account for dynamics. For maintenance activities no significant effect has been observed.

Travel time in leisure activities in negatively associated with subsistence activity. Both activity and travel time decreases for an increase in leisure travel time. The relation is positive with travel time for subsistence activity.

6. CONCLUSION

The aim of the paper was to determine the relationships between life-cycle events and dynamics of time allocation to activity and travel. By developing a structural model we analyzed the effect of several life-cycle events on changes in activity and travel time allocation. The results support the arguments presented in the paper. We observe significant impacts of life cycle events on the time allocations. Moreover, the effects are varied and differ according to the type of event in the existence, intensity and direction.

The findings reasonably support the three hypotheses regarding life cycle events and activity travel dynamics that we proposed. Events related to subsistence activities, such as, new job and starting university affect time allocation to subsistence activities. Events related to big household changes, such as, residential relocation and children starting school influence time allocation to maintenance and leisure activity-travel. Events related to changes in civil status, which potentially changes the social network size and composition, such as getting married/separated/divorced/cohabitation influence the time allocation to maintenance and leisure activities. We also have found additional effects that all events affect time allocation to leisure activities in varying intensity and direction. This is most likely because leisure activities are the most flexible and discretionary of all. However, this finding also acts as an indicator that life cycle events are associated with social networks since they are key in most leisure activity planning. Any change in leisure activity time allocation potentially means change in the type and pattern of maintenance of social networks which in turn affects their size and composition. Consequently, dynamics of social networks are associated with dynamics of activity travel behavior (*27*).

In terms of interdependencies between activity and travel time allocation dynamics, we observe that the causal association is not one way from subsistence activities as we had conceptualized.

There were some missing issues (key events, such as, child birth and details of residential move) in the analysis. This was primarily due to lack of data. In terms of data, there are some errors and biases associated with retrospective surveys, which were inevitable in this case. Nonetheless the study presents a first analysis. Details on dynamics of other aspects of activity and travel (mode choice, activity-travel party) should be included in a comprehensive model. This remains for the future agenda.

The results of this study contribute to the deeper understanding of long term dynamics in activity and travel behavior. The findings are important since research on long term dynamic time allocation is relatively limited in transportation and travel behavior research. The paper should aid in developing travel demand forecasting models and formulating more comprehensive analytical models.

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