Cross sectional and longitudinal relationships among information and telecommunication technologies, daily time allocation to activity and travel, and modal split using structural equation modeling

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ABSTRACT

This paper investigates the impacts of information and communication technologies on daily time allocation to various activities and travel, and on modal split for a substantially large sample of 1480 persons interviewed repeatedly. Employing structural equations we explore the relationships among different activity and travel time use indicators and daily frequencies of travel mode use. Using the Puget Sound Transportation Panel (PSTP) database collected in 1997 and 2000, time use for a specific activity (subsistence, maintenance, and leisure) and traveling, as well as travel frequencies of each mode (driving alone, shared ride, transit, bike, walk, and others) are modeled as regression functions of cross-sectional and longitudinal information. The information analyzed includes personal and household socio-demographics in the year 2000 and changes in socio-demographics, and telecommunication technology ownership and availability between the years 1997 and 2000. Overall, the effect of mode frequencies on duration of activities appears to be much stronger than the effect of activity duration on the trips made. Household and person factors are also important determinants of travel behavior even when we control for activity participation. Throughout the study the effect of social and economic changes on activity and travel behavior was found to be asymmetric. Similarly the effect of changes in ICT technology use was asymmetric and very different depending on the location of the technology (home or work) and the mobility of the technology itself.

INTRODUCTION

During the last decade, we have experienced explosive growth and continued proliferation in Information and Communications Technology (ICT) (i.e., widespread use of computers and the Internet, email, cellular phone, laptop, Personal Digital Assistant (PDA), etc). This may have already altered the ways people conduct their daily life and also the way in which business is conducted.

In fact, transportation researchers such as Golob (2000) and Golob and Regan (2001) argue that traditional accessibility measures alone, such as travel time, distance or generalized travel costs, are no longer appropriate under these circumstances, because through ICT people experience a change in their virtual accessibility and gain access to a rapidly growing range of activities without the more traditional spatio-temporal limitations and constraints. For example, ICT makes it possible for people to work at any place (telecommute) and to buy goods without a physical trip to the store (teleshopping or e-commerce). It therefore allows people more flexibility to arrange their schedules, and eventually changes their activity and travel pattern. Access to technologies and knowledge about ICT are not uniform across the population. These substantial and differential impacts of ICT create the need for research on the present and future impacts of telecommunications on activity and travel behavior.

To date we have seen a substantial amount of research on the relationship between ICT and transportation, and a variety of theoretical relationships have been proposed (Salomon, 1986, Mokhtarian, 1990 and 2000, Marker and Goulias, 2000). In addition, many hypotheses have been empirically tested mostly in the telecommuting arena (Pendyala, Goulias, and Kitamura, 1991, Mokhtarian, 1997, Mokhtarian and Salomon, 1996). However, most studies focused on the potential impacts of ICT on mobility, especially the degree of substitution and complementarity between transportation and telecommunications (Mokhtarian, 1990 and 2000, Golob, 2000). There is still a gap in the literature and few studies exist to date on other aspects of ICT impacts on activity and travel behavior.

For example, as activity-based approaches to travel demand modeling are emerging a need arises to examine the relationship between time allocation and technology ownership and use. In addition, with longitudinal data the effect of changes in technology ownership and use on time allocation can be examined in more detail and compared to the effect of other social and demographic changes we all experience. To accomplish this, we developed a structural equation model adopting a broader perspective that includes time use indicators and modal split indicators in a system of equations viewed as dependent variables jointly to capture activity and travel patterns in a day. The complex relationships among social and demographic change, information and telecommunication technology change, daily time allocation, and mode choice are then studied using traditional hypotheses testing of regression coefficients and an examination of the magnitude of effects an indicator has on another indicator considering both the direct influence of one factor on another and any other indirect effects in a system of non recursive relationships. Some of the more recent simultaneous equation modeling applications in travel behavior data analysis are used here for guidance in developing the model system and in interpreting some of the findings. The activity classification follows Golob (1998) and Chung and Ahn (2002). Explanatory variable definition and model specification is based on a series of more recent studies using subsets of the PSTP and reported in Kim and Goulias (2003) and Goulias and Kim (2003) using a single equation regression approach. Figure 1 shows the conceptual framework of the model. A plethora of relationships can be studied using this system. For example, the correlation among the amount of time allocated to subsistence, maintenance, leisure, and travel, as well as the total number of trips by the most important modes (drive alone, car sharing, public transportation, walking, biking, and all other modes used) can be estimated. The model system is designed to parallel other past studies and for this reason variables at the household and person level are also used. In addition, some specific variables to the database in PSTP are also employed to account for stratification and potential participation fatigue. A key variant of the model system that sets it aside from other studies is the inclusion of "experience" variables. Using information between 1997 and 2000 a large set of variables is defined to capture the changes in social and economic circumstances experienced by each respondent and include them as explanatory variables of the behavior in the year 2000. The second element that characterizes the research work here is the study of ICT on activity and travel behavior considered jointly with all the other determinants of travel behavior.

[Figure 1 Conceptual Model]

Within this framework, we are addressing the following key questions:

- What is the relationship among different activities and travel in terms of time use when we control for many other exogenous factors?
- What is the relationship among the use of different travel modes and activity participation?
- Are there systematic differences in time use for specific activities and travel among population segments and is the time use changing with changes on person and household socio-demographics and ICT ownership and availability?
- Are there systematic differences in daily mode choice among population segments and is the mode choice changing with changes on person and household socio-demographics and ICT ownership and availability?

The remainder of this paper is organized as follows. In the next section, a brief description of the data used is provided, followed by model formulation and estimation results. The paper ends with summary and conclusions.

DATA USED

The database used in this study is from the Puget Sound Transportation Panel (PSTP), which is the first general-purpose urban household panel survey in the four-county region including Seattle in the United States. Unlike traditional transportation surveys, in PSTP, a household questionnaire and a two-day travel diary are administered on the same households and the persons within the households repeatedly over time. Each survey occasion is called a wave. PSTP started in the fall of 1989, and it continues until today with sample size of approximately 1700 households per wave. To date, there have been ten waves in PSTP, and the survey data for wave 10 is currently under preparation.

Each survey includes three groups of data that are household demographics, persons' social and economic information, and reported travel behavior. Trip information was collected using a travel diary. In the travel diary each driving age person reports every trip made during two consecutive weekdays, which remained approximately the same throughout the panel years. Each trip contains information about trip purpose, type, mode, starting and ending time, origin and destination, and distance. Additional details about the panel can be found in Murakami and Ulberg, 1997 and Goulias, Kilgren, and Kim, 2003. For the analysis in this study, we used the data from 1480 persons in 688 households who provided detailed information in both waves 7 and 9 for all the variables used in this analysis.

In the original trip data of PSTP, the mode chosen for each trip has been classified into 17 different types: car, carpool, vanpool, bus, para-transit, taxi, walking, bicycle, motorcycle, school bus, drive-on ferry, walk-on ferry, monorail, boat, train, airplane, and other. In this case, car indicates a single occupant vehicle trip mode by car/truck/sport utility vehicle (SUV), while carpool and vanpool implies an official carpool or vanpool as well as an informally shared trip mode by car/truck/suv or van. The public transportation trips are mostly by bus and taxi. To make this analysis tractable the modes have been grouped into:

- Single occupant vehicle (car),
- Shared ride (carpool and vanpool),
- Transit (bus, para-transit, and taxi),
- Walk,
- Bike, and
- Others (all other categories).

In addition, activity types have been also grouped into:

- Subsistence (work, school, and college),
- Maintenance (shopping, personal business, appointment, and errand/picking-up/dropping-off), and
- Leisure (free time, recreation/exercise, visiting, and home staying).

[Table 1 A Selection of Sample Characteristics]

Total activity duration includes the amount of time each person spends in activities, including in–home activities (between the first and last out–of–home activity), during a day but neither before the first trip in the morning nor after the final return to home in the evening. Total travel time is the total amount of time spent by a person traveling during the day.

Table 1 shows the number of persons, households, and a few social and demographic characteristics of the sample. It also shows amount of time dedicated to various activities and traveling as well as travel frequency of each mode during the two interview days in wave 7 (1997) and wave 9 (2000). As expected, people show a similar pattern of activity and travel behavior between the two days and between the two waves, except for activity and travel durations between the waves. The rather large discrepancy in activity and travel durations is most likely a result of genuine change but also the use of different schemes for trip purposes in the travel survey between the waves. In the year 2000, the respondents spent an average of 230.1 minutes in subsistence activity, 46.7 minutes in maintenance activity, 93.3 minutes in leisure activity, and 74.4 minutes in travel per day. The respondents are heavily dependent on cars/truck/SUV for their travel mode. Traveling alone with car/truck/SUV is the most popular mode accounting for 56.6 percent of total trips, while bike is the least used mode accounting for only 0.5 percent.

The bottom of Table 1 contains information about technology ownership and use with focus on the more modern technologies. Computer and Internet at home are the two fastest growing technologies. Computers at work appear to be stabilizing at 50% of the sample, and although Internet use at work is increasing, it did not reach the level of penetration of computers at work. Cellular phone ownership is increasing even faster than computers and the Internet, causing a potential negative impact on pagers. Laptop computers and PDA are used by a small sample segment as reported.

MODEL FORMULATION

Variables Used

Two groups of activity-travel variables are used as the endogenous variables in the model. The first group of the endogenous variables is total amount of time dedicated to a specific activity (subsistence, maintenance, and leisure) and traveling in a day. The second group is the frequency of trips by a specific mode (SOV, shared mode, transit, walk, bike, other modes) a person makes in a day.

Endogenous Variables		Descriptions
Activity and Travel Durations	Sdur	Total subsistence activity duration per day (min)
	Mdur	Total maintenance activity duration per day (min)
	Ldur	Total leisure activity duration per day (min)
	Ttime	Total travel time per day (min)
Travel Frequency by Mode	Ssov	Number of trips per day by driving alone
	Shared	Number of trips per day by shared ride
	Transit	Number of trips per day by transit
	Walk	Number of trips per day by walking
	Bike	Number of trips per day by bike
	Others	Number of trips per day by other modes

For exogenous variables, four groups of variables were used: household-level variables, person-level variables, time-related variables, and ICT variables. Table 2 provides an inventory of all the exogenous variables used for this study. We used cross-sectional information in the year 2000 as well as longitudinal information between the years 1997 and 2000 about household-level and person-level social, economic, demographic characteristics and ICT ownership and availability.

[**Table 2 Exogenous Variables used in This Study]**

To account for task allocation and roles within the household, number of adults, number of children by age group as well as vehicles owned and income representing resource availability are included as exogenous variables. In addition, in order to account for the sampling stratification of the panel participants, the county of residence and sample indicators (TRANSIT, CARPOOL) are also included as exogenous variables.

Indicators for changes in household and person characteristics, such as increase or decrease in car-ownership, changes in household composition, and changes in employment, were used to examine the effect of the changes on time use and mode choice.

Two types of time variables are also included. The first type is person-level time elapsed in panel since the first time participating and it can capture two effects: a) a genuine change in activity and travel behavior by a person during the time of her/his panel participation; and b) possible travel diary and/or panel fatigue in reporting trips. The second type is the set of day of week indicators to account for different activity and travel behaviors among weekdays (weekends are not targeted in PSTP) and a correlation between the first and second diary day.

To examine the effect of changes in information and telecommunication technology between the years 1997 and 2000, we defined indicator variables for four groups of persons for each ICT:

- Persons that started using these technologies some time after 1997 and they are using them in 2000 (*new users*);
- Persons that stopped using these technologies since 1997 (*past users*);
- Persons that never used them (*non users*); and
- Persons that started some time before 1997 and never stopped (*experienced users*).

The use of structural equation modeling techniques is employed in this study, due to their capability to estimate a set of simultaneous equations capturing the interrelationship among a large number of endogenous and exogenous variables. This modeling technique has been used in the analysis of travel behavior since the middle of 1970's. A comprehensive and informative review of many transportation research applications using structural equation models (SEM) can be found in Golob (2003).

Structural Equation Model (SEM)

The general SEM with latent variables consists of two parts: 1) measurement model and 2) structural model. The measurement model specifies how latent variables are indicated by the observed variables, while the structural model specifies the causal relationships among the latent variables and describes the causal effects of the exogenous variables on the endogenous variables. The measurement model can be further classified into the measurement model for the endogenous variables (y) and the measurement model for the exogenous variables (x). The matrix formulation of the general SEM with latent variables is defined as follows:

Measurement model for y: $y = \Lambda_y \eta + \varepsilon$ (1)

Measurement model for x: $x = \Lambda_x \xi + \delta$ (2)

Structural model: $\eta = \mathrm{B}\eta + \Gamma\xi + \zeta$ (3)

where $y = p \times 1$ vector of observed endogenous variables.
$x = q \times 1$ vector of observed exogenous variables.
$\eta = m \times 1$ vector of latent endogenous variables.
$\xi = n \times 1$ vector of latent exogenous variables.
$\varepsilon = p \times 1$ vector of measurement errors in y.
$\delta = q \times 1$ vector of measurement errors in x.
$\Lambda_y = p \times m$ matrix of coefficients of the regression of y on η.
$\Lambda_x = q \times n$ matrix of coefficients of the regression of x on ξ.
$\mathrm{B} = m \times m$ matrix of coefficients of the η-variables in the structural relationships.
$\Gamma = m \times n$ matrix of coefficients of the ξ-variables in the structural relationships.
$\zeta = m \times 1$ vector of equation errors in the structural relationships.

Given the complexity and operational difficulties in estimation of a full SEM, it is rarely found in practice (Golob, 2003). Like in the SEM used in this paper, the most common SEM application is SEM with observed variables. Since no latent variables are involved in the SEM, the measurement models for x and y are dropped. Structural equations models with observed variables are therefore reduced to the following form:

$$y = \mathrm{B}y + \Gamma x + \zeta \qquad (4)$$

where $y = p \times 1$ vector of observed endogenous variables.
$x = q \times 1$ vector of observed exogenous variables.
$\mathrm{B} = p \times p$ matrix of coefficients of the y-variables.
$\Gamma = p \times q$ matrix of coefficients of the x-variables.
$\zeta = p \times 1$ vector of equation errors.

In the SEM with observed variables, y and x are assumed to exactly represent the latent η and ξ, respectively. So the number of y variables equals the number of η variables (p=m) and the number of x variables equals the number of ξ variables (q=n).

SEM is a covariance–based model, because structural equations systems are estimated by covariance analysis. In the procedure, the difference between the sample covariances and the covariances predicted by the model is minimized, instead of minimizing the difference between observed and predicted individual values. The underlying theory of this estimation procedure is that the population covariance matrix of the observed variables (Σ) is a function of a set of parameters:

$$\Sigma = \Sigma(\theta) = \begin{bmatrix} \text{covariance matrix of y} & \text{covariance matrix of y and x} \\ \text{covariance matrix of x and y} & \text{covariance matrix of x} \end{bmatrix}$$

$$= \begin{bmatrix} (I - \mathrm{B})^{-1}(\Gamma\Phi\Gamma' + \Psi)[(I - \mathrm{B})^{-1}]' & (I - \mathrm{B})^{-1}\Gamma\Phi \\ \Phi\Gamma'[(I - \mathrm{B})^{-1}]' & \Phi \end{bmatrix} \quad (5)$$

where Φ = covariance matrix of x.
Ψ = covariance matrix of ζ .

The matrix $\Sigma(\theta)$ basically consists of three covariance matrices. The unknown parameters $\mathrm{B}, \Gamma, \Phi, \text{and } \Psi$ are simultaneously estimated by finding the parameters such that the covariance matrix ($\hat{\Sigma}$) implied by the model is as close as possible to the sample covariance matrix (S). To know when the estimates are as close as possible, a fitting function that is to be minimized is defined.

Estimation Methods

The most commonly used estimation methods include maximum-likelihood (ML), unweighted least squares(ULS) , generalized least squares (GLS), scale-free least squares (SLS), and asympotically distribution-free (ADF). The choice of the estimation method depends mainly on the assumption of the probability distribution, the type of variables, and sample size. ML estimation method assuming a multivariate normal distribution was employed for this study. ML estimation was found fairly robust to deviation of multivariate normality and sample size commonly used in transportation research (Golob, 2003). The ML fitting function that is minimized is:

$$F_{ML} = \log|\Sigma(\theta)| + tr(S\Sigma^{-1}(\theta)) - \log|S| - (p + q) \quad (6)$$

Decomposition of Effects

In SEM, there are three type of effects of one variable on another: direct, indirect, and total effects. The direct effects, which are estimated as $\mathrm{B} \text{ and } \Gamma$, are the influences of one variable on another that is not mediated by any other variable, while the indirect effects are ones mediated by at least one intervening variable. The total effects are the sum of the direct and indirect effects. It should be noted that interpreting a model with the direct effects only provides misleading conclusions when the direct and the total effects are very different. It is the total effects that should be used in interpretation. As implied in equation (5), the decomposition of effects for SEM with observed variables can be made as follows:

Decomposition of Effects		Effects on Y
Effect of x	Total Effect	$(I - \mathrm{B})^{-1}\Gamma$
	Direct Effect	Γ
	Indirect Effect	$(I - \mathrm{B})^{-1}\Gamma - \Gamma$
Effect of y	Total Effect	$(I - \mathrm{B})^{-1} - I$
	Direct Effect	B
	Indirect Effect	$(I - \mathrm{B})^{-1} - I - \mathrm{B}$

Goodness-of-fit Indices

Many indices of fit have been developed to evaluate the goodness-of-fit of a SEM. However, which measure should be used is still one of difficult and controversial issues (Arbuckle and Wothke, 1999). The commonly used measures are:

- χ^2 **statistic and its p-value:** χ^2 statistic measures the discrepancy between the observed covariance matrix and the one predicted by the model. It is calculated by multiplying the minimum value of the fit function by N (sample size)-1. So the smaller the chi-square value is the better model is. Its p-value indicates the probability that the discrepancy between the two matrices is due to sampling variation. However, this measure is problematic for the case of large sample size and when the multivariate normality assumption is violated.

- χ^2 **/df:** The use of the ratio of chi-square to its degrees of freedom is also suggested. The problem of this measure is that it is not clear what value of ratio should be used for a satisfactory model. One of the rules of thumb for good fit suggested by Bryne (1989) is that the ratio should be less than 2.

- **Normed Fit Index (NFI):** NFI measures the proportion reduction in minimum discrepancy by comparing a proposed model to a baseline model. The independence model in which the observed variables are assumed to be uncorrelated with each other, is most often used as the baseline model. In general, the NFI value greater than 0.90 indicates that the model fit is acceptable. Other goodness-of-fit indices calculated by comparisons to a baseline model, include Relative Fit Index (RFI), Incremental Fit Index (IFI), Tucker Lewis Index (TLI) and Comparative Fit Index (CFI). For all these indices, values close to 1 indicate a good fit. Hu and Bentler (1999) and Yu and Muthen (2001) suggested a cut-off value of 0.95 for TLI and CFI for good models.

- **Akaike Information Criterion (AIC):** Using Akaike information criterion based on Bayesian theory allows us to compare the performance of models with quite different number of parameters. Smaller values are associated with better models.

- **Browne-Cudeck Criterion (BBC):** BBC is a similar measure to AIC, but it assigns a slightly greater penalty for model complexity than does AIC. So this measure favors more parsimonious models.

- **Root Mean Square Error of Approximation (RMSEA):** RMSEA is a measure of the population discrepancy per degree of freedom to compensate for the effects of model complexity. In general, a value of RMSEA for a good model should be less than 0.05 (Browne and Cudeck, 1993) or 0.06 (Hu and Bentler, 1999, Yu and Muthen, 2001). Browne and Cudeck (1993) also suggested that the entire 90% confidence interval for RMSEA should be less than 0.05 for a good fit.

- **Critical Number (CN):** CN is the largest sample size for which one would accept the hypothesis that a model is correct. Generally, a CN of 200 or more indicates a satisfactory fit with a significance level of 0.05 (Tanka, 1987).

MODEL RESULTS

Figure 2 and Table 3 provide an overview of the complex relationships found among the amount of time allocated to activities in each day by each person and the number of trips made by each mode. The sum of the number of trips by mode is also the frequency of activity episodes that involve the change of an activity location. In the section with label "goodness-of-fit indices" we see that every indicator reviewed in a previous section shows a model with excellent fit to the data.

[Figure 2 Path Diagram Among Endogenous Variables Based on Direct Effects]

[Table 3 Total, Direct, and Indirect Effects among Endogenous Variables]

Cross-sectional Effects

Turning to the effects of variables, travel time does not influence any other variable and therefore implicitly treated as the outcome of all the other indicators. One way of looking at the relationships among daily subsistence duration (sdur), daily maintenance duration (mdur), daily leisure duration (ldur), and daily travel time (ttime) is to consider the possible effect of a minute more in one type of activity on another. Subsistence duration's effect is very clear: persons that work longer are more likely to spent less time in leisure (-0.129) and maintenance (-0.062). Golob (1998) claims this as evidence of time budgeting by individuals and their households. In another analysis, however, Goulias, Kilgren, and Kim (2003) find extreme variation in "budgeting" and the existence of multiple groups with very different budgets. Note also the circular effect through the indirect effects. The direct effect on leisure, however, is the highest. As expected persons that spend more time working/studying are also more likely to travel longer (0.032). Time expenditure on maintenance (e.g., shopping) has also a negative effect on leisure and subsistence and considerably larger than the two effects of subsistence before. The total effect of leisure on maintenance is positive and small and the total effect of maintenance on leisure in negative (inhibiting) and large. None of the effects is larger than one (no substitution one for one minute) and the largest appears to be the "trade-off" between maintenance and leisure (1 minute of maintenance leads to a third less leisure).

Moving to the effects of activity daily durations on the number of trips by mode a striking finding is the overall lack of influence time allocation has on the modal frequencies. As expected it is more likely that the number of episodes determine activity duration and not the other way around. In addition, persons with longer durations are more likely to make more trips driving alone and with others in the same private car than to take the bus. Leisure duration appears to have a positive effect on bicycle trips but very small, while, the use of most "others" modes are inhibited by longer durations of any activity type.

When we consider the number of trips effect on time allocation we see a few systematic relationships. The frequency of traveling by transit and other modes are accompanied by a positive and fairly large effect on the amount of time allocated to activities on maintenance (34.7 minutes per day for transit) but also leisure (18.8 minutes) and as expected travel time (17.8 minutes). Walking has a similar effect on maintenance and exactly the opposite on leisure duration. Using a car either alone or with others is accompanied by longer daily allocations to maintenance, leisure, and travel but not subsistence. The difference between direct and total effect in car sharing lead us to believe that using a simultaneous equation technique is a worthwhile exercise leading to better understanding of the effect one variable has on another. Overall, the effect of mode frequencies on duration of activities appears to be much stronger than the effect of activity duration on the trips made.

Effects among the use of travel modes generally seem to be quite different in magnitude as well as in signs by direction. These different effects by direction may be due to the fact that each mode has unique characteristics, thus each pair of modes cannot be a complete alternative to each other. For example, SOV has positive and small total effects (0.121) on transit, while transit on SOV has negative and large effects (-0.691). So the net effects of transit on SOV (-0.570) indicate that transit could be a good substitute to SOV, but not true vice versa. In the case between shared modes and transit, shared modes has small, negative total effects (-0.039) on transit, while transit has relatively large, positive effects (0.381) on shared modes, resulting in the net effect of (0.342). It indicates that transit has enhancement effects on share mode. However, it should be noted that caution is required in interpretation, because trip frequency by each mode in this study was treated as continuous variables rather than counting variables, which may influence the magnitude of the coefficient.

In PSTP sampling follows a stratification scheme that requires us to either weight the observations or to include as explanatory variables factors used in the stratifications (e.g., county of residence and household classification with respect to usual mode used). The first five rows of Table 4 show the inclusion of these variables explains some of the variation in the endogenous variables and as expected there are large differences among the segments that reside in different counties.

[Table 4 Total and Direct Effects of Cross-sectional Household-level Variables on Endogenous Variables]

In the same table, the effect of children is very interesting showing that in general households with more children spend more time engaging in leisure and second in maintenance and as expected travel time. The effect on the number of trips is positive for persons in households with children in the age group of 1 to 17. These effects, however, are not the same as when the person analyzed resides in a household with more adults. The use of transit and walking, however, is consistently lower for persons in households that have more children of any age and more other adults. Interestingly, the presence of more adults in the household is also accompanied by lower frequencies of driving alone and almost similar and opposite effect on sharing rides. Presumably adults in multi adult households share rides more often. The household income indicators show that in general wealth is accompanied with spending more time in all activities and traveling more in terms of number of trips and time traveling. To account for the second coding allowed in the PSTP stated household income, we also include variable, MHINC.

[Table 5 Total and Direct Effects of Cross-sectional Person-level and Time-related Variables on Endogenous Variables]

Table 5 shows the effect of person-level and time-related variables. As expected, working more than 5 times a week and attending a school or college are the two largest factors on subsistence activity durations. Additionally, having a driver's license or bus pass are the largest contributors to total travel time in a day. Males in the age group of 35-64 spend more time on subsistence activity and traveling than the other age groups. People have different patterns of time use within the various occupation types. For example, people having a professional or managerial position spend more time on subsistence but less on leisure than those in other occupations. On the other hand, people who are in secretarial or sales occupations are engaged less in subsistence and more in leisure activities. The sales person travels more than any other occupation as expected.

In terms of mode use, SOV usage is higher for students, people having a secretary or sales occupation, and people who work more than 5 times per week. In addition, it is found that a driver's license is one of main factors on mode choice. Having a driver's license has positive effects on the use of SOV and shared mode, but negative effects on the other modes, especially on transit. On the other hand, having a bus pass discourages the use of SOV, and expectedly encourages the use of transit. Being a male has negative effects on frequency of SOV, shared mode, and walking, but positive effects on transit, bike, and others. Older generations seem to use transit less often but SOV more often than other age groups.

Time related variables in the bottom of table 5 confirms people's pattern of life during the weekday. They have quite different patterns in time use between Thursday and Friday. On Thursday, people work the longest and spend the least time on leisure. On the contrary, it is on Friday that people work the least and spend the most time on leisure during the weekdays. In terms of mode frequency, there are some similarities between Tuesday and Friday, and between Wednesday and Thursday, but the two groups of days show almost opposite patterns of mode frequency.

Longitudinal Effects

One of the advantages in using panel data is our ability to measure change in a variable and concomitant effect on another. From a travel behavior viewpoint it is also interesting and useful to know if there is behavioral symmetry when these changes happen. For example, is the difference in activity participation the same when a household looses a car and when it gains a car? Or what is the effect of an arrival of a young child and how is that different from that child growing older? This type of effects and relationships were hypothesized some time ago (Goodwin, Kitamura, and Meurs, 1990) but not tested empirically.

[Table 6 Total and Direct Effects of Household-level & Person-level Change Variables on Endogenous Variables]

The variables reported in Table 6 aim to describe the difference in activity and travel behavior among households and individuals that experienced diametrically opposed events such as increase in children versus a decrease in children, increase in household cars versus a decrease in household cars, as well as personal changes such as change in employment status. Figures 3 and 4 provide a pictorial representation of this lack of symmetry.

[Figure 3 Total Effects of Changes in Household and Personal Characteristics on Time Use]

[Figure 4 Total Effects of Changes in Household and Personal Characteristics on Mode Frequencies]

Very important for transportation policy is the effect of car ownership on travel but also the effect of providing incentives for bus use. An increase in the number of vehicles in the household has no effect in the use of transit but a decrease has exactly the opposite from what one would expect. Most likely because this was accompanied by lower activity participation that in turn leads to lower trip making overall.

Tables 4, 5, and 6 allow us to perform some additional calculations. Regression coefficients defined for a group of indicators are relative to the excluded group (implicitly assumed to have a zero coefficient). For example, let's assume a man in a young couple with a child finds a professional job working 5 days per week, thus increasing his household income from low income to mid income. Also, let's assume the man buys a car resulting in one car available in the household. From this situation, we can compute how much more time he spends on subsistence activity in a day as a difference from the time he spent previously as an unemployed man in a couple with a child and no car in the household. This would compute as follows: (0.956 + 178.074 + 10.425 - 11.985 - 1.136 -19.246 + 94.609) = 251.697, which means on average 251.697 minutes more on subsistence activity than his previous status. Similar calculations lead to 38.735 minutes less on maintenance activity, 2.039 trips more by SOV, 0.597 trips more by sharing a car than his previous status. Examining travel time, however, we see that fewer trips do not necessarily mean less traveling. For example, these same users that make less frequent trips may also travel long distances or in congested conditions for longer times.

Longitudinal Effects of ICT

Turning to the effects of information and communication technologies on activity participation and travel summarized in Table 7, again we see evidence of a lack of symmetry and linearity. The ICT effect, however, is not always asymmetrical. For example, acquiring access to a computer at work is accompanied by 34 more minutes of work. In contrast, loosing access of computer at work is accompanied by 41 less minutes working. The net difference is a small number of about 7 minutes per day. When we look at these same two ICT variables and maintenance duration, gaining access of computers shows a negative 6.368 and loosing access a positive 6.398 demonstrating an almost perfectly symmetric effect. Then, turning to leisure duration we see that gaining access has an effect that is more than three times (-14.063) that of loosing access (4.135).

[Table 7 Total and Direct Effects of ICT Variables on Endogenous Variables]

Comparing the experienced information and telecommunication users to the new users and non-users, we find the overall effect of computers and Internet at work to be an increase in subsistence participation and a decrease in leisure participation accompanied by less trip making. However, computers and Internet at home have the opposite effect on the two activities. The example is the amount of time allocated for leisure by the persons that are experienced users of computers at work and at home. The first group spends 20 minutes less in leisure per day and the second 22.7 more. As the average values of the ICT user indicators show we have an increase in technology users over time at home but not a substantial increase at work/school. The new computer users are 20.8% at home and new Internet users are 32% at home. The first group spends more time in all activities and travels more and the second group spends less time in activities and travels less. New users of computers at home, use public transportation more often and bike more often but exactly the opposite happens to the new users of the internet at home but at lower levels because of less trip making in general. Laptop users increase rapidly if one considers that experienced laptop users are 2% of the sample and new users are 3.2%. Experienced mobile technology users are also diverse but the experienced mobile technology users spend less time in subsistence and traveling, except that experienced cellular phone users travel more.

[Figure 5 Total Effects of ICT Variables on Time Use and Mode Frequencies]

Figure 5 provides a pictorial summary of the lack of symmetry and linearity in time use and mode frequencies for ICT user groups at different stages. One interesting occurrence found in Figure 5 is a quite different pattern in time use between the experienced laptop users and the new laptop users. Experienced and new users of ICT generally show a similar pattern in time use and trip frequency by mode (in Table 7, the same sign of the coefficients but different coefficients in magnitude). However, this is not the case for the laptop. Although both the experienced users and new users spend less time on subsistence activity than non-users and past-users, their magnitudes are quite different (-91.257 for experienced users and –1.515 for new users). In addition, these two groups of laptop users have the opposite patterns of time use for other activities and traveling (they have almost the same magnitude of coefficients but different signs). This opposite pattern of the two groups holds true for trips by SOV and shared modes.

SUMMARY AND CONCLUSIONS

In this paper a plethora of relationships among the most popular travel behavior indicators are studied. A system of equations is first defined that includes as dependent variables the amount of time allocated to subsistence, maintenance, leisure, and travel, as well as the total number of trips by the most important modes (drive alone, car sharing, public transportation, walking, biking, and all other modes used). The model system is designed to parallel other past studies and for this reason variables at the household and person level are used. In addition, some specific variables in the PSTP database are also employed to account for stratification and potential participation fatigue.

A key variant of the model system that sets it aside from other studies is the inclusion of "experience" variables. Using information between 1997 and 2000 a large set of variables is defined to capture the changes in social and economic circumstances experienced by each respondent and include them as explanatory variables of the behavior in 2000. In this way we can detect if the experience of a specific event can explain behavior and if its opposite event has the same but of opposite sign effect on behavior. In the striking majority of social and economic changes we find significant, many times substantial, and asymmetric effects.

The second element that characterizes the research work here is the study of ICT on activity and travel behavior considered jointly with all the other determinants of travel behavior. Comparing experienced information and telecommunication users to the new users and to the non-users we find a variety of interesting results. The overall "technology" effect seems to depend on the location of technology. The overall effect of computers and Internet at work shows an increase in subsistence participation and a decrease in leisure participation accompanied by less trip making. Additionally, computers and Internet at home have the opposite effect on the two activities. As the average values of these variables show we have an increase in technology users over time at home but not a substantial increase at work/school. The new computer users are 20.8% at home and new Internet users are 32% at home. The first group spends more time in all activities and travels more and the second group spends less time in activities and travels less. New users of computers at home, use public transportation more often and bike more often but exactly the opposite happens to the new users of the internet at home but at lower levels because of less trip making in general.

The model system presented in this paper proves to be a very powerful tool in understanding activity and travel behavior in a social and economic context and allows one to examine behavioral aspects in unprecedented detail for hypotheses testing. This model system, however, has also some limitations due to some fundamental assumptions. All the dependent variables were assumed to be multivariate normally distributed and continuous. This may influence the values of the effects and their significance (although testing and experimentation with single equation models lead to similar conclusions).

For this reason one potential expansion of the work here is to use a limited dependent variable formulation for the time allocation indicators (to account for the large concentration of persons at zero minutes per day) and to use a count data regression formulation for the frequencies by mode.

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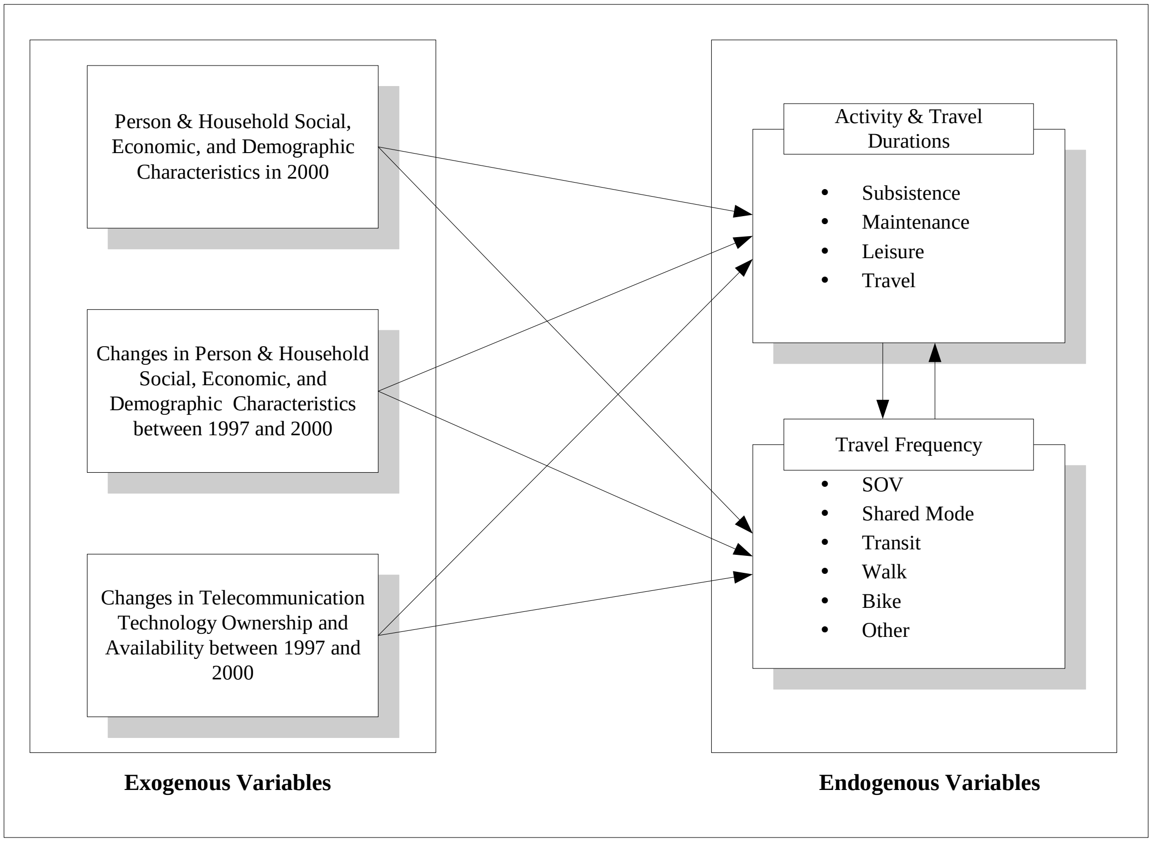

Figure 1 Conceptual Model

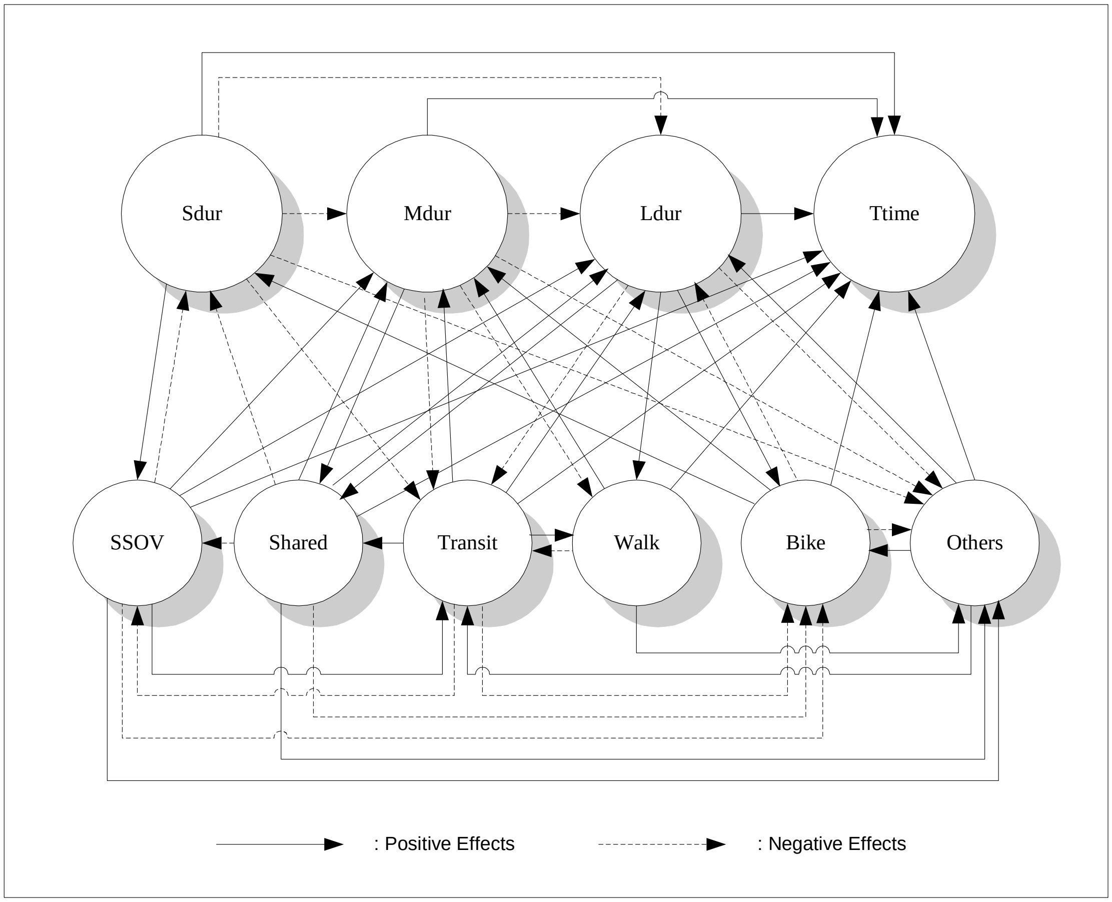

Figure 2 Path Diagram Among Endogenous Variables Based on Direct Effects

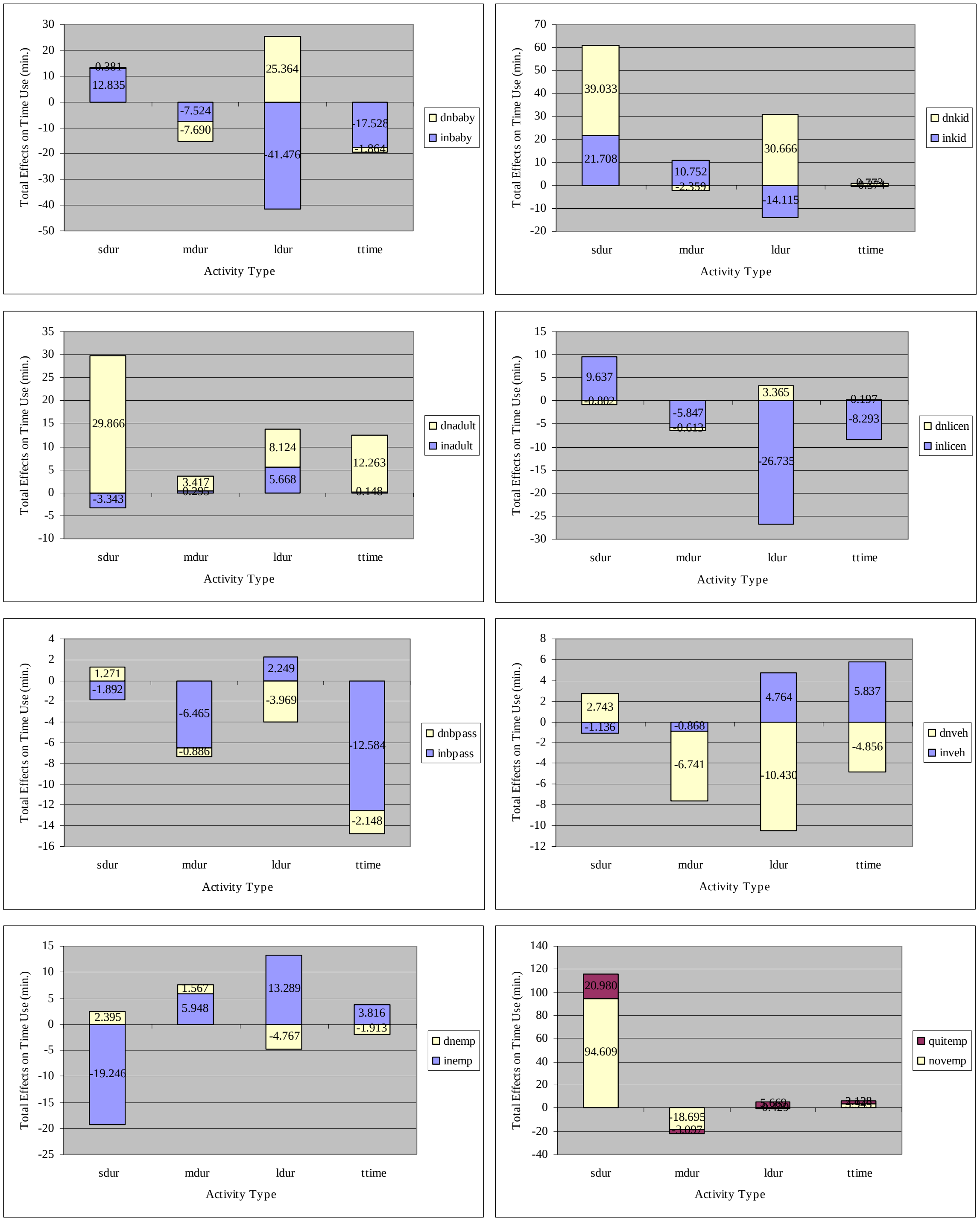

Figure 3 Total Effects of Changes in Household and Personal Characteristics on Time Use

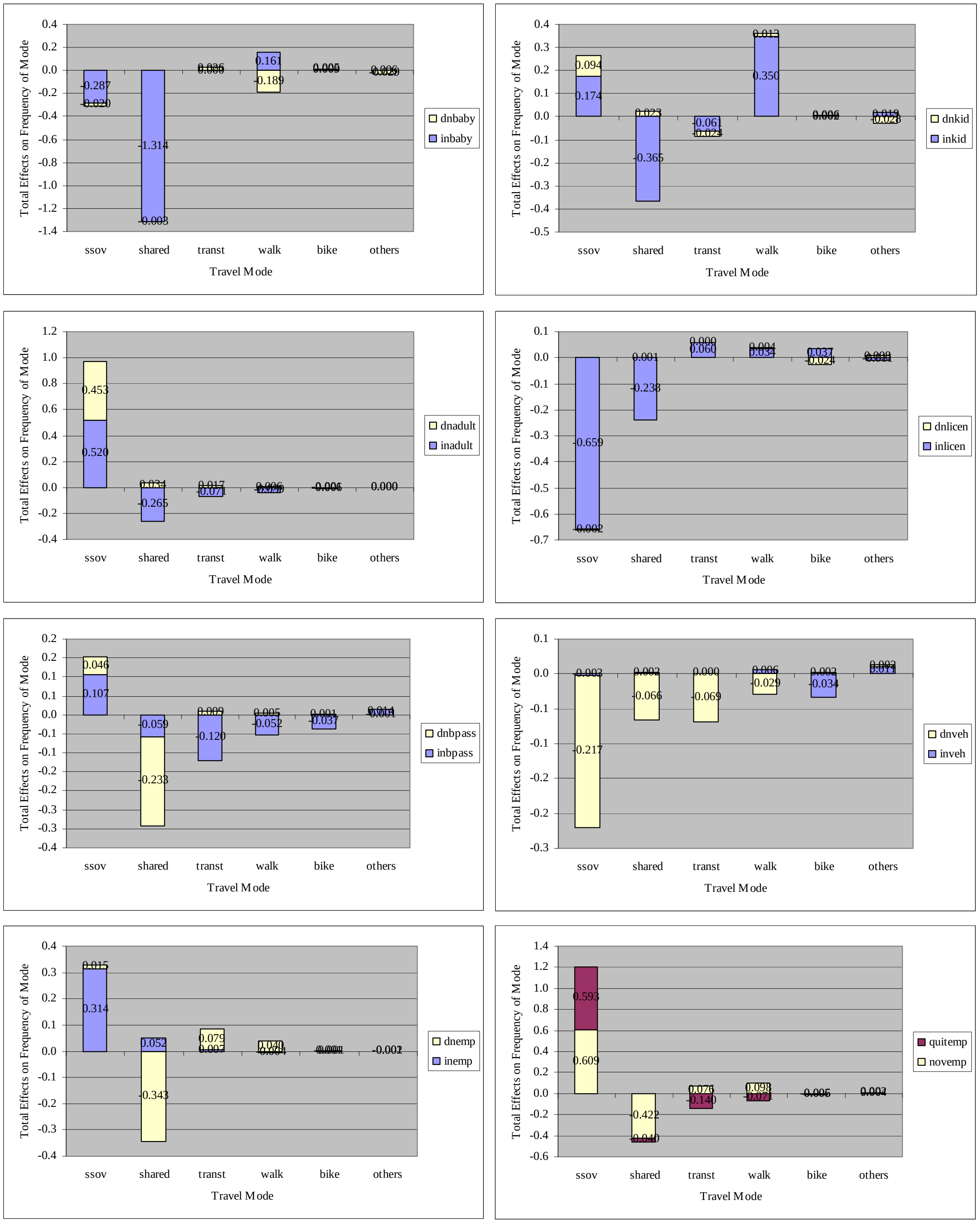

Figure 4 Total Effects of Changes in Household and Personal Characteristics on Mode Frequencies

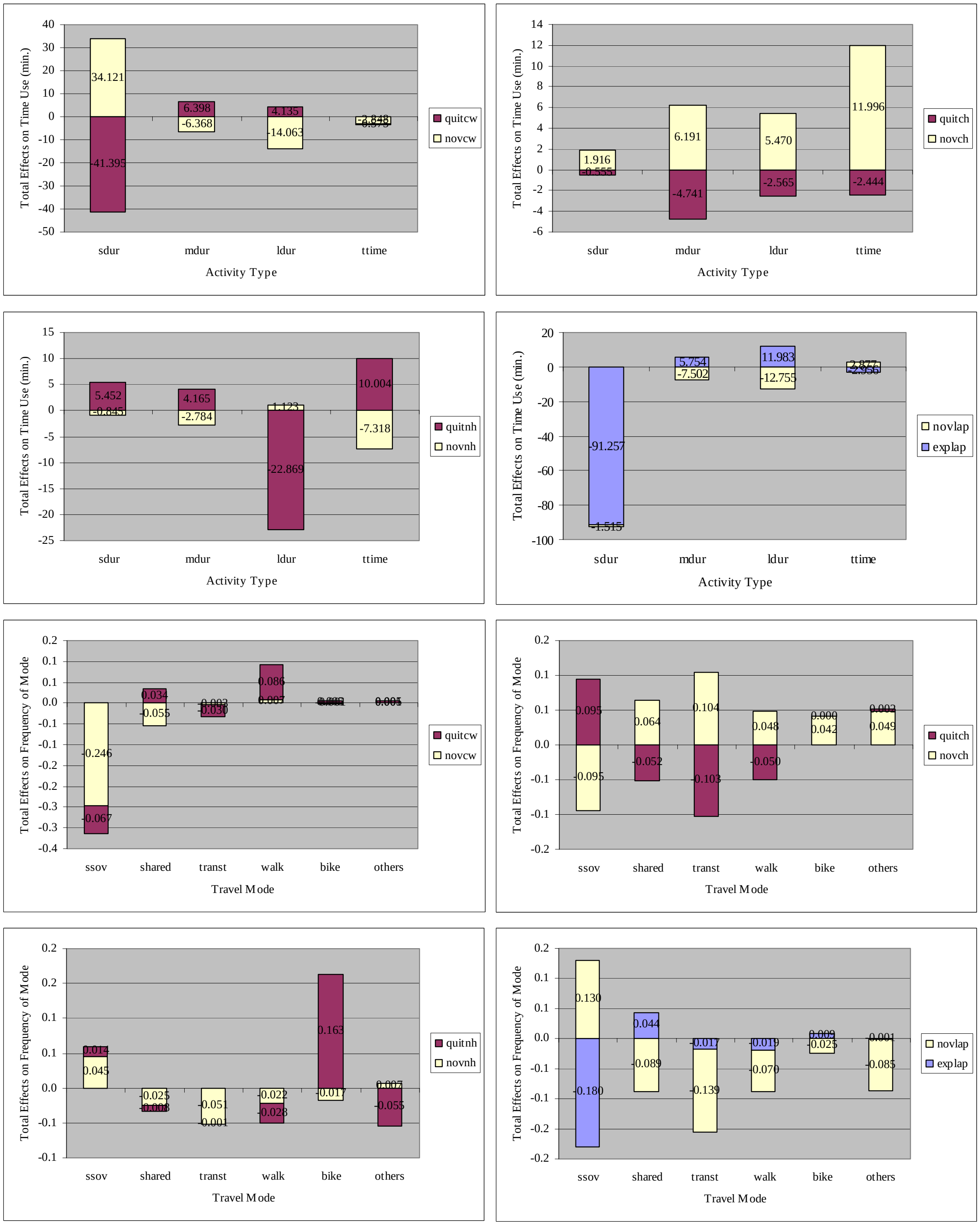

Figure 5 Total Effects of ICT Variables on Time Use and Mode Frequencies

Table 1 A Selection of Sample Characteristics

Characteristics			Wave 7 (1997)	Wave 9 (2000)
Number of persons in the sample			1480	1480
Number of households in the sample			866	866
Person & Household	Percent of males in the sample		46.9	46.9
	Number of employed persons in the sample		859	881
	Number of persons in household		2.5	2.5
	Number of cars per household		2.2	2.2
Activity & Travel	Total amount of time in subsistence activities (min.)	Day 1	275.0	235.3
		Day 2	265.2	224.9
	Total amount of time in maintenance activities (min.)	Day 1	43.3	46.4
		Day 2	39.4	46.9
	Total amount of time in leisure activities (min.)	Day 1	109.8	93.5
		Day 2	106.9	93.0
	Total amount of time traveling (min.)	Day 1	84.7	75.0
		Day 2	79.0	73.8
Travel Mode*	Total Number of trips per person	Day 1	4.57	4.08
		Day 2	4.30	3.98
	Number of trips driving alone per person (%*)	Day 1	2.52 (55.1)	2.31 (56.6)
		Day 2	2.37 (55.1)	2.25 (56.5)
	Number of trips by shared modes per person (%*)	Day 1	1.57 (34.4)	1.34 (32.8)
		Day 2	1.52 (35.3)	1.34 (33.7)
	Number of trips by transit per person (%*)	Day 1	0.19 (4.2)	0.17 (4.2)
		Day 2	0.15 (3.5)	0.15 (3.8)
	Number of trips by walking per person (%*)	Day 1	0.20 (4.4)	0.20 (4.9)
		Day 2	0.16 (3.7)	0.18 (4.5)
	Number of trips by biking per person (%*)	Day 1	0.02 (0.4)	0.02 (0.5)
		Day 2	0.02 (0.5)	0.02 (0.5)
	Number of trips by other modes per person (%*)	Day 1	0.06 (1.3)	0.05 (1.2)
		Day 2	0.07 (1.6)	0.05 (1.3)
Information & Communication Technology**	Number of persons who use computer regularly (%**)	At home	751 (50.7)	982 (66.4)
		At work	700 (47.3)	717 (48.4)
	Number of persons who use the Internet regularly (%**)	At home	458 (30.9)	896 (60.5)
		At work	438 (29.6)	544 (36.8)
	Number of persons having cellular phone (%**)		419 (28.3)	685 (46.3)
	Number of persons having pager (%**)		156 (10.5)	129 (8.7)
	Number of persons having laptop (%**)		71 (4.8)	79 (5.3)
	Number of persons having PDA (%**)		6 (0.4)	38 (2.6)

**% over total number of trips per person*
*** % over total number of person in the sample*

Table 2 Exogenous Variables Used in This Study

Household level	CARPOOL	Indicator, 1= household is sampled from carpool class; 0=otherwise
	TRANSIT	Indicator, 1= household is sampled from public transit class; 0=otherwise
	KITSAP	Indicator, 1= living in Kitsap County; 0=otherwise
	PIERCE	Indicator, 1= living in Pierce County; 0=otherwise
	SNOHO	Indicator, 1= living in Snohomish County; 0=otherwise
	TOT1_5	Number of children in the household who are less than 6 years old
	TOT6_17	Number of children in the household who are between 6 and 17 years old
	TOTADULT	Number of adults in the household who are 18 years old or older
	MIDINC	Indicator, 1= $35,000 ≤ household income < $75,000; 0=otherwise
	HIGHINC	Indicator, 1= $75,000 ≤ household income; 0=otherwise
	MHINC	Indicator, 1= $35,000 ≤ household income; 0=otherwise
	DKINC	Indicator, 1=household income is unknown; 0=otherwise
	CAR1	Indicator, 1= one car household; 0=otherwise
	CAR2	Indicator, 1= two car household; 0=otherwise
	CAR3_	Indicator, 1= two car household; 0=otherwise
	INBABY	Indicator, 1=an increase in the number of children < 6 years in the household between waves; 0=otherwise
	DNBABY	Indicator, 1= a decrease in the number of children < 6 years in the household between waves; 0=otherwise
	INKID	Indicator, 1= an increase in the number of kids whose age is 6-17 in the household between waves; 0=otherwise
	DNKID	Indicator, 1= a decrease in the number of kids whose age is 6-17 in the household between waves; 0=otherwise
	INADULT	Indicator, 1=an increase in the number of adults in the household between waves; 0=otherwise
	DNADULT	Indicator, 1=a decrease in the number of adults in the household between waves; 0=otherwise
	INLICEN	Indicator, 1=an increase in the number of drivers license holders between waves; 0=otherwise
	DNLICEN	Indicator, 1=a decrease in the number of drivers license holders between waves; 0=otherwise
	INBPASS	Indicator, 1=an increase in bus pass holders in the household between waves; 0=otherwise
	DNBPASS	Indicator, 1=a decrease in bus pass holders in the household between waves; 0=otherwise
	INVEH	Indicator, 1=an increase in the number of cars in the household between waves; 0=otherwise
	DNVEH	Indicator, 1=a decrease in the number of cars in the household between waves; 0=otherwise
	DNEMP	Indicator, 1=an increase in the number of employed persons in household between waves; 0=otherwise
	DNEMP	Indicator, 1=a decrease in the number of employed persons in household between waves; 0=otherwise
Person level	MALE	Indicator, 1=male; 0=female
	YOUNG	Indicator, 1=18≤ age ≤ 34; 0=otherwise
	MIDAGE	Indicator, 1=35≤ age ≤ 64; 0=otherwise
	PROF	Indicator, 1=having professional occupation; 0=otherwise
	MANAG	Indicator, 1=having managerial occupation; 0=otherwise
	SECRE	Indicator, 1=having secretarial occupation; 0=otherwise
	SALES	Indicator, 1=having sales occupation; 0=otherwise
	WK5	Indicator, 1=working outside of home for 5+ times a week; 0=otherwise
	DPUPIL	Indicator, 1= student; 0=otherwise
	DLICEN	Indicator, 1= having driver's license; 0=otherwise
	DBPASS	Indicator, 1= having bus pass; 0=otherwise
	EXPEMP	Indicator, 1= started getting employed outside home in both waves; 0=otherwise
	NOVEMP	Indicator, 1= employed outside home in wave 9 only; 0=otherwise
	QUITEMP	Indicator, 1= employed outside home in wave 7 but not in wave 9;0=otherwise
Time related	PELAP	Time duration (No. of year) for person in panel
	PELAP2	Square of time duration for person in panel
	TUE	Indicator, 1=diary on Tuesday; 0=otherwise
	WED	Indicator, 1=diary on Wednesday; 0=otherwise
	THU	Indicator, 1=diary on Thursday; 0=otherwise
	FRI	Indicator, 1=diary on Friday; 0=otherwise
Information and Communication Technology	EXPCW	Indicator, 1= using computer at work/school in both waves; 0=otherwise
	NOVCW	Indicator, 1= started using computer at work/school after wave 7; 0=otherwise
	QUITCW	Indicator, 1= stopped using computer at work/school after wave 7; 0=otherwise
	EXPCH	Indicator, 1= using computer at home in both waves; 0=otherwise
	NOVCH	Indicator, 1= started using computer at home after wave 7; 0=otherwise
	QUITCH	Indicator, 1= stopped using computer at home after wave 7; 0=otherwise
	EXPNW	Indicator, 1= using Internet at work/school in both waves; 0=otherwise
	QUITNW	Indicator, 1= stopped Internet at work/school after wave 7; 0=otherwise
	EXPNH	Indicator, 1= using Internet at home in both waves; 0=otherwise
	NOVNH	Indicator, 1= started using Internet at home after wave 7; 0=otherwise
	QUITNH	Indicator, 1= stopped using Internet at home after wave 7; 0=otherwise
	EXPCEL	Indicator, 1= using cell phone in both waves; 0=otherwise
	QUITCEL	Indicator, 1= stopped using cell phone after wave 7; 0=otherwise
	EXPPAG	Indicator, 1= using pager in both waves; 0=otherwise
	NOVPAG	Indicator, 1= started using pager after wave 7; 0=otherwise
	EXPLAP	Indicator, 1= using laptop computer in both waves; 0=otherwise
	NOVLAP	Indicator, 1= started using laptop computer after wave 7; 0=otherwise
	NOVLAP	Indicator, 1= started using PDA after wave 7; 0=otherwise

Table 3 Total, Direct, and Indirect Effects among Endogenous Variables

Causal Endogenous Variables		Resulting Endogenous Variables									
		sdur	mdur	ldur	ttime	ssov	shared	transt	walk	bike	others
Sdur	total	-0.019	-0.062	-0.129	0.032	0.002	0.000	-0.000	0.000	0.000	-0.000
	direct	0.000	-0.094	-0.225	0.020	0.002	0.000	-0.000	0.000	0.000	-0.000
	indirect	-0.019	0.033	0.096	0.012	0.000	0.000	0.000	0.000	0.000	0.000
Mdur	total	-0.041	-0.181	-0.311	0.024	0.000	0.004	-0.002	-0.004	0.000	-0.000
	direct	0.000	0.000	-0.383	0.058	0.000	0.006	-0.003	-0.003	0.000	-0.000
	indirect	-0.041	-0.181	0.072	-0.034	0.000	-0.002	0.001	-0.001	0.000	0.000
Ldur	total	-0.003	0.003	-0.120	-0.012	0.000	0.001	-0.001	0.000	+0.000	-0.001
	direct	0.000	0.000	0.000	0.015	0.000	0.001*	-0.001	0.001	+0.000	-0.001
	indirect	-0.003	0.003	-0.120	-0.027	0.000	0.000	0.000	-0.001	0.000	0.000
Ttime	total	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	direct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	indirect	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ssov	total	-10.491	13.452	30.448	11.654	-0.069	0.121	0.026	-0.002	-0.007	-0.002
	direct	-10.074	11.813	30.497	9.456	0.000	0.000	0.094	0.000	-0.019	0.021
	indirect	-0.417	1.639	-0.049	2.198	-0.069	0.121	-0.068	-0.002	0.013	-0.023
Shared	total	-5.644	3.934	17.626	9.538	-0.206	0.037	-0.039	-0.023	-0.004	0.003
	direct	-7.330	7.917	24.923	11.543	-0.218	0.000	0.000	0.000	-0.017	0.020
	indirect	1.686	-3.984	-7.298	-2.005	0.012	0.037	-0.039	-0.023	0.013	-0.017
Transt	total	4.059	34.685	18.765	17.877	-0.691	0.381	-0.243	0.365	-0.003	-0.012
	direct	0.000	31.913	60.697	21.346	-0.815	0.216	0.000	0.596	-0.021	0.000
	indirect	4.059	2.772	-41.932	-3.469	0.123	0.165	-0.243	-0.231	0.018	-0.012
Walk	total	-1.918	31.807	-10.625	6.346	0.124	0.121	-0.189	-0.210	0.006	0.048
	direct	0.000	44.333	0.000	5.453	0.000	0.000	-0.153	0.000	0.000	0.067
	indirect	-1.918	-12.525	-10.625	0.893	0.124	0.121	-0.036	-0.210	0.006	-0.020
Bike	total	29.075	22.214	-121.959	-7.157	0.072	-0.041	-0.005	-0.149	-0.132	-0.293
	direct	33.985	35.926	-79.274	5.494**	0.000	0.000	0.000	0.000	0.000	-0.407
	indirect	-4.910	-13.711	-42.685	-12.651	0.072	-0.041	-0.005	-0.149	-0.132	0.115
Others	total	7.519	12.001	89.963	38.195	-0.051	0.193	0.029	0.044	0.248	-0.167
	direct	0.000	0.000	133.056	38.460	0.000	0.000	0.176	0.000	0.249	0.000
	indirect	7.519	12.001	-43.094	-0.265	-0.051	0.193	-0.147	0.044	-0.002	-0.167
Goodness-of–fit Indices		Chi-Square =305.287, d.f.=471, P-value=1.000 Chi-Square/d.f =0.650 NFI=0.998 TLI =1.007 CFI =1.000 RMSEA =0.000, 90 Percent C.I. of RMSEA=(0.000 0.000), Probability(RMSEA <=0.05) =1.000 CN=5049									

Note: A direct effect value of 0.000 for a variable indicates that the variable was constrained to 0 in the model, because of its insignificance at 90% level. However, the values of –0.000 or +0.000 indicates that the effects are less than 0.0005 in magnitude, but significant at 95 % level.
** Significant at 90% level; all others are significant at 95% level, except for***
*** insignificant at 90 % level*

Table 4 Total and Direct Effects of Cross-sectional Household-level Variables on Endogenous Variables

Exogenous Variables		Endogenous Variables									
		sdur	mdur	ldur	ttime	ssov	shared	transt	walk	bike	others
carpool	total	-0.640	-3.391	-5.915	-0.426	-0.531	0.728	-0.043	-0.020	-0.019	-0.062
	direct	0.000	0.000	0.000	0.000	-0.406	0.764	0.000	0.000	0.000	-0.078
transit	total	3.525	-3.007	19.800	9.761	-0.418	0.116	0.490	0.314	0.005	-0.001
	direct	0.000	-28.411	0.000	0.000	0.000	0.000	0.584	0.000	0.000	0.000
kitsap	total	2.472	3.643	-4.885	5.253	-0.031	0.022	0.038	0.009	0.068	0.286
	direct	0.000	0.000	-37.454	-7.123	0.000	0.000	0.000	0.000	0.000	0.312
pierce	total	0.329	4.858	0.914	1.056	-0.075	0.046	0.080	-0.082	-0.003	-0.008
	direct	0.000	6.584*	0.000	0.000	0.000	0.000	0.092	-0.117	0.000	0.000
snoho	total	17.973	-3.623	1.345	6.499	-0.051	0.005	0.106	-0.105	-0.003	-0.009
	direct	17.598	0.000	0.000	5.448	0.000	0.000	0.091	-0.179	0.000	0.000
tot1_5	total	-4.226	2.945	13.197	7.141	-0.154	0.776	-0.029	-0.017	-0.003	0.002
	direct	0.000	0.000	0.000	0.000	0.000	0.749	0.000	0.000	0.000	0.000
tot6_17	total	-4.791	5.002	17.449	5.045	0.077	0.564	-0.014	-0.011	0.003	0.023
	direct	0.000	0.000	0.000	-3.171	0.198	0.516	0.000	0.000	0.000	0.026
totadult	total	1.936	-1.139	-6.552	-1.632	-0.382	0.259	-0.017	-0.076	0.000	-0.003
	direct	0.000	5.429	0.000	0.000	-0.343	0.277	0.000	-0.065	0.000	0.000
midinc	total	10.425	1.011	16.658	11.370	0.219	0.209	0.047	0.036	0.009	0.040
	direct	13.852*	-5.680	0.000	3.569	0.282	0.171	0.043*	0.000	0.000	0.048
highinc	total	15.557	7.352	16.201	10.327	0.405	0.341	0.006	-0.006	0.039	0.033
	direct	20.798	0.000	0.000	0.000	0.453	0.277	0.000	0.000	0.037	0.053
mhinc	total	-3.339	18.628	10.350	6.619	0.287	0.113	-0.018	-0.057	0.011	0.054
	direct	0.000	16.730	0.000	0.000	0.304*	0.000	0.000	0.000	0.000	0.070
dkinc	total	0.000	0.000	0.000	11.018	0.000	0.000	0.000	0.000	0.000	0.000
	direct	0.000	0.000	0.000	11.018	0.000	0.000	0.000	0.000	0.000	0.000
car1	total	-11.985	-3.901	15.675	-12.155	0.678	0.704	-1.050	-0.605	0.000	-0.019
	direct	0.000	41.714	39.615*	0.000	0.000	0.932	-1.206	0.000	0.000	0.000
car2	total	-11.855	-9.982	34.722	-13.414	0.714	0.668	-1.084	-0.595	0.007	-0.032
	direct	0.000	35.906	60.416	0.000	0.000	0.912	-1.244	0.000	0.000	0.000
Car3_	total	-10.688	-12.274	27.915	-16.643	0.799	0.394	-1.113	-0.610	0.007	-0.031
	direct	0.000	36.451	58.894	0.000	0.000	0.665	-1.295	0.000	0.000	0.000

Note: A direct effect value of 0.000 for a variable indicates that the variable was constrained to 0 in the model, because of its insignificance at 90% level.
** Significant at 90% level; all others are significant at 95% level.*

Table 5 Total and Direct Effects of Cross-sectional Person-level and Time-related Variables on Endogenous Variables

Exogenous Variables		Endogenous Variables									
		sdur	mdur	ldur	ttime	ssov	shared	transt	walk	bike	others
male	total	38.030	-12.521	-7.504	6.312	-0.104	-0.280	0.033	-0.012	0.012	0.040
	direct	34.509	-6.465	0.000	8.351	-0.215	-0.207	0.000	-0.062	0.000	0.050
young	total	0.533	4.551	2.462	2.346	-0.091	0.050	0.099	0.048	0.000	-0.002
	direct	0.000	0.000	0.000	0.000	0.000	0.000	0.131	0.000	0.000	0.000
midage	total	0.656	5.608	3.034	2.890	-0.112	0.062	0.122	0.059	-0.001	-0.002
	direct	0.000	0.000	0.000	0.000	0.000	0.000	0.162	0.000	0.000	0.000
prof	total	0.956	-0.175	-10.935	3.307	-0.115	0.190	0.092	0.048	0.035	-0.002
	direct	0.000	-6.580*	-14.597	0.000	0.000	0.185	0.102	0.000	0.044	0.000
manag	total	0.081	-0.066	-21.401	0.297	-0.010	-0.025	0.019	-0.003	-0.006	0.017
	direct	0.000	0.000	-24.321	0.000	0.000	0.000	0.000	0.000	0.000	0.000
secre	total	-3.387	4.343	9.829	-4.572	0.301	0.039	0.008	-0.001	-0.002	-0.001
	direct	0.000	0.000	0.000	-8.335	0.323	0.000	0.000	0.000	0.000	0.000
sales	total	-4.995	6.404	14.496	5.548	0.443	0.058	0.012	-0.001	-0.003	-0.001
	direct	0.000	0.000	0.000	0.000	0.476*	0.000	0.000	0.000	0.000	0.000
wk5	total	178.074	-22.055	-22.621	9.542	0.337	-0.138	0.067	0.010	0.012	-0.008
	direct	180.039	-11.155	0.000	4.799*	0.000	0.000	0.000	-0.077	0.031	0.000
dpupil	total	94.030	-26.197	-12.568	-1.830	0.259	-0.588	0.074	0.110	-0.001	0.005
	direct	92.378	-22.889	0.000	0.000	0.000	-0.442*	0.000	0.000	0.000	0.000
dlicen	total	20.883	4.912	39.699	14.082	1.613	0.064	-0.073	-0.222	-0.014	-0.009
	direct	38.085	0.000	0.000	0.000	1.525	0.000	-0.206	-0.192	0.000	0.000
dbpass	total	30.441	-1.471	-13.367	10.741	-0.364	0.082	0.500	0.047	0.036	0.046
	direct	26.144	-14.301	-31.699	0.000	0.000	0.000	0.527	-0.247	0.036	0.060
pelap	total	-0.155	1.819	-0.466	0.754	0.006	0.031	-0.016	0.076	0.004	0.004
	direct	0.000	-1.509	0.000	0.000	0.000	0.025	0.000	0.091	0.003	0.000
pelap2	total	0.012	-0.197	0.066	-0.039	-0.001	-0.001	0.001	-0.005	0.000	0.000
	direct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.006	0.000	0.000
tue	total	14.324	6.244	0.457	3.339	-0.042	0.223	0.027	-0.001	-0.004	-0.001
	direct	15.661*	5.634*	0.000	0.000	0.000	0.182	0.054	0.000	0.000	0.000
wed	total	18.784	-2.836	0.519	6.279	0.028	-0.012	0.016	-0.044	0.004	0.018
	direct	18.836	0.000	0.000	5.104	0.000	0.000	0.000	-0.062	0.000	0.025*
thu	total	31.287	-2.003	-14.633	6.580	0.057	-0.027	0.015	0.005	-0.006	0.009
	direct	31.858	0.000	-11.966	5.422	0.000	0.000	0.000	0.000	0.000	0.000
fri	total	-1.811	1.262	5.655	9.050	-0.066	0.333	-0.013	-0.007	-0.001	0.001
	direct	0.000	0.000	0.000	5.990	0.000	0.321	0.000	0.000	0.000	0.000

Note: A direct effect value of 0.000 for a variable indicates that the variable was constrained to 0 in the model, because of its insignificance at 90% level.
** Significant at 90% level; all others are significant at 95% level.*

Table 6 Total and Direct Effects of Household-level & Person-level Change Variables on Endogenous Variables

Exogenous Variables		Endogenous Variables									
		sdur	mdur	ldur	ttime	ssov	Shared	transt	walk	bike	others
inbaby	total	12.835	-7.524	-41.476	-17.528	-0.287	-1.314	0.000	0.161	0.009	0.006
	direct	0.000	0.000	0.000	0.000	-0.599	-1.217	0.000	0.167	0.000	0.000
dnbaby	total	0.381	-7.690	25.364	-1.864	-0.020	-0.003	0.026	-0.189	0.005	-0.029
	direct	0.000	0.000	25.879	0.000	0.000	0.000	0.000	-0.244	0.000	0.000
inkid	total	21.708	10.752	-14.115	-0.374	0.174	-0.365	-0.061	0.350	0.002	0.019
	direct	20.710*	0.000	0.000	0.000	0.000	-0.392	0.000	0.427	0.000	0.000
dnkid	total	39.033	-2.359	30.666	0.773	0.094	0.023	-0.024	0.013	0.006	-0.028
	direct	39.936	0.000	40.696	0.000	0.000	0.000	0.000	0.000	0.000	0.000
inadult	total	-3.343	0.295	5.668	0.148	0.520	-0.265	-0.071	-0.039	-0.001	0.000
	direct	0.000	0.000	0.000	0.000	0.411	-0.259*	-0.121	0.000	0.000	0.000
dnadult	total	29.866	3.417	8.124	12.263	0.453	0.034	0.017	0.006	-0.006	0.000
	direct	34.883	0.000	0.000	6.326	0.414	0.000	0.000	0.000	0.000	0.000
inlicen	total	9.637	-5.847	-26.735	-8.293	-0.659	-0.238	0.060	0.034	0.037	-0.011
	direct	0.000	0.000	0.000	0.000	-0.682	-0.183*	0.093	0.000	0.037	0.000
dnlicen	total	-0.802	-0.613	3.365	0.197	-0.002	0.001	0.000	0.004	-0.024	0.008
	direct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.028*	0.000
inbpass	total	-1.892	-6.465	2.249	-12.584	0.107	-0.059	-0.120	-0.052	-0.037	0.014
	direct	0.000	0.000	0.000	-10.051	0.000	0.000	-0.159	0.000	-0.043	0.000
dnbpass	total	1.271	-0.886	-3.969	-2.148	0.046	-0.233	0.009	0.005	0.001	-0.001
	direct	0.000	0.000	0.000	0.000	0.000	-0.225*	0.000	0.000	0.000	0.000
inveh	total	-1.136	-0.868	4.764	5.837	-0.003	0.002	0.000	0.006	-0.034	0.011
	direct	0.000	0.000	0.000	5.558	0.000	0.000	0.000	0.000	-0.039	0.000
dnveh	total	2.743	-6.741	-10.430	-4.856	-0.217	-0.066	-0.069	-0.029	0.002	0.002
	direct	0.000	0.000	0.000	0.000	-0.293	0.000	-0.081	0.000	0.000	0.000
inemp	total	-19.246	5.948	13.289	3.816	0.314	0.052	0.007	-0.004	-0.001	-0.001
	direct	-15.663*	0.000	0.000	0.000	0.370	0.000	0.000	0.000	0.000	0.000
dnemp	total	2.395	1.567	-4.767	-1.913	0.015	-0.343	0.079	0.040	0.001	-0.002
	direct	0.000	0.000	0.000	0.000	0.000	-0.362	0.086	0.000	0.000	0.000
expemp	total	202.274	-13.913	-26.542	10.082	1.025	-0.718	-0.026	0.006	-0.020	0.002
	direct	207.993	0.000	0.000	6.462	0.437	-0.600	-0.132	0.000	0.000	0.000
novemp	total	94.609	-18.695	-0.429	3.945	0.609	-0.422	0.076	0.098	-0.006	0.004
	direct	97.839	-20.190	0.000	0.000	0.387*	-0.334	0.000	0.000	0.000	0.000
quitemp	total	20.980	-3.097	5.669	2.128	0.593	-0.040	-0.140	-0.071	-0.005	0.002
	direct	26.819*	0.000	0.000	0.000	0.427	0.000	-0.207	0.000	0.000	0.000

Note: A direct effect value of 0.000 for a variable indicates that the variable was constrained to 0 in the model, because of its insignificance at 90% level.
** Significant at 90% level; all others are significant at 95% level.*

Table 7 Total and Direct Effects of ICT Variables on Endogenous Variables

Exogenous Variables		Endogenous Variables									
		Sdur	mdur	ldur	ttime	ssov	shared	transt	walk	bike	others
expcw	total	80.446	-10.356	-20.034	-1.284	-0.274	-0.083	0.004	0.018	0.006	0.036
	direct	76.868	0.000	0.000	0.000	-0.453	0.000	0.000	0.000	0.000	0.041
novcw	total	34.121	-6.368	-14.063	-2.848	-0.246	-0.055	-0.003	0.007	-0.001	0.001
	direct	31.263	0.000	0.000	0.000	-0.330	0.000	0.000	0.000	0.000	0.000
quitcw	total	-41.395	6.398	4.135	-0.575	-0.067	0.034	-0.030	0.086	0.005	0.005
	direct	-41.971	0.000	0.000	0.000	0.000	0.000	0.000	0.120	0.000	0.000
expnw	total	5.690	-4.318	-8.281	5.581	-0.181	-0.423	0.010	0.013	0.023	0.064
	direct	0.000	0.000	0.000	9.547	-0.276	-0.390	0.000	0.000	0.000	0.078
quitnw	total	0.324	-5.371	1.794	-1.072	-0.021	-0.020	0.032	-0.133	-0.001	-0.008
	direct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.169	0.000	0.000
expch	total	-2.831	6.622	22.699	10.719	0.228	0.079	0.054	0.029	0.001	-0.011
	direct	0.000	0.000	13.991	6.105	0.295	0.000	0.076	0.000	0.000	0.000
novch	total	1.916	6.191	5.470	11.996	-0.095	0.064	0.104	0.048	0.042	0.049
	direct	0.000	0.000	0.000	7.056	0.000	0.000	0.136	0.000	0.029	0.071
quitch	total	-0.555	-4.741	-2.565	-2.444	0.095	-0.052	-0.103	-0.050	0.000	0.002
	direct	0.000	0.000	0.000	0.000	0.000	0.000	-0.137	0.000	0.000	0.000
expnh	total	-16.479	1.039	2.164	-0.534	-0.033	0.008	-0.003	-0.003	0.002	0.000
	direct	-16.801	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
novnh	total	-0.845	-2.784	1.123	-7.318	0.045	-0.025	-0.051	-0.022	-0.017	0.007
	direct	0.000	0.000	0.000	-6.248	0.000	0.000	-0.068	0.000	-0.020*	0.000
quitnh	total	5.452	4.165	-22.869	10.004	0.014	-0.008	-0.001	-0.028	0.163	-0.055
	direct	0.000	0.000	0.000	11.346*	0.000	0.000	0.000	0.000	0.188	0.000
expcel	total	-1.499	-0.024	-4.238	7.743	-0.036	0.138	0.003	-0.001	-0.025	0.015
	direct	0.000	0.000	-11.155*	6.063	0.000	0.143*	0.000	0.000	-0.025	0.000
quitcel	total	4.452	-5.708	-12.919	-4.945	-0.395	-0.051	-0.011	0.001	0.003	0.001
	direct	0.000	0.000	0.000	0.000	-0.424	0.000	0.000	0.000	0.000	0.000
exppag	total	-30.531	1.925	4.009	-0.989	-0.060	0.015	-0.006	-0.006	0.003	0.000
	direct	-31.129	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
novpag	total	-0.511	6.506	30.782	0.821	0.040	0.063	-0.067	0.164	0.010	-0.016
	direct	0.000	0.000	37.413	0.000	0.000	0.000	0.000	0.201	0.000	0.000
explap	total	-91.257	5.754	11.983	-2.956	-0.180	0.044	-0.017	-0.019	0.009	-0.001
	direct	-93.043	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
novlap	total	-1.515	-7.502	-12.755	2.877	0.130	-0.089	-0.139	-0.070	-0.025	-0.085
	direct	0.000	0.000	0.000	10.078	0.000	0.000	-0.180	0.000	0.000	-0.104
novpda	total	42.700	-2.693	-5.607	1.383	0.084	-0.021	0.008	0.009	-0.004	0.001
	direct	43.536	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: A direct effect value of 0.000 for a variable indicates that the variable was constrained to 0 in the model, because of its insignificance at 90% level.
** Significant at 90% level; all others are significant at 95% level.*