ON MODELING HETEROGENEITY IN SOLO AND JOINT "WITH WHOM" TRIP MAKING

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ABSTRACT

Complex behaviour patterns in the activity-travel based modelling system would include joint activities and travel participations. Activities and travel involving multiple persons from the same household or their wider society would arise as a result of a collective decision process that requires its participants to fit periods of joint activity-travel engagement into individual schedules while considering their own needs along those of other persons. There is an increasing realization that such household interdependencies have to be accommodated explicitly within comprehensive activity-based models. Currently, most of the existing activity-based models of transport demand typically assume an individual decision-making process.
The main objective of this study is to empirically investigate individuals' solo versus joint "with whom" travel participation. This was based on two-day activity and travel diary data from Cairo, Egypt. The proposed modelling approach entails the modelling of the decision of household members to participate in travel as (1) solo, (2) joint with only household members, (3) joint with only non- household members, and (4) joint with combinations of household and non- household members.

In order to achieve the study objective, a mixed logit model was developed. The proposed modelling framework is distinguished from previous related studies in several capabilities. <u>First</u>, it accommodates heterogeneity in responsiveness to solo and joint "with whom" travel participation. Therefore, intra-individual variations in joint travel participation could be accommodated, where some of prior literature assumed homogeneity in responsiveness to attributes of solo and joint alternatives across individuals. <u>Second</u>, it could determine the possible sources of any solo and joint preference heterogeneity that may exist. <u>Third</u>, the model is capable to capture correlation between members of the same household and within-individuals over different travel episodes. Thus **correlations** due to shared unobservable factors among solo and joint travel participation were also analyzed. <u>Fourth</u>, the developed model is more disaggregated as it is capable to capture the dependent variable at an individual-level rather than at a role-level (head/spouse) or at a particular segment-level (male/female).

Empirical evidences support many of our hypotheses regarding joint "with whom" travel participations. Household traditions, social roles, and lifestyle were found to be the main factors which affect joint travel participation.

Keywords: household interactions, activity based modelling, activity diary survey, mixed logit models, taste heterogeneity

INTRODUCTION

Activity-based approaches have been recognized as a powerful methodology to model human travel behaviour because of their realistic representations of the complete activity schedule of individuals over a period of a day or a longer unit of time (Bhat and Koppelman, 1999; Pendyala and Goulias, 2002). The activity-based approach differs from trip based analysis by accounting explicitly the fact that the demand for travel is derived from the need to participate in activities distributed in space and time (Pas and Harvey, 1997). A major trend of the activity based approach to travel demand analysis is that people's activity and travel patterns are governed by numerous constraints and opportunities. Constraints may include modal constraints (related to modal availability and accessibility), scheduling constraints (work and school schedules), household and personal constraints (household obligations, physiological needs), and institutional constraints (opening and closing hours of business institutions. Chapin (1974) proposed a motivational foundation of activity-based approaches to travel demand analysis in which societal constraints and inherent individual motivations interact to shape revealed activity participation patterns. There is an increasing recognition that the influence of such constraints and motivations must be recognized for building up travel behaviour models which have received considerable attention in the specialized literature (Arentze and Timmermans, 2002; Pendyala *et al.* 1998).

In fact, household members interact in many ways during their daily activity and travel related decision-making. Individuals undertake both independent and joint activities/travel as part of their overall daily activity-travel patterns. The joint activities are often motivated by social factors (as indicated by Townsend, 1987) such as desire for companionship and altruism (i.e., enabling activity participation of the mobility-constrained), or by resource constraints (i.e., limited vehicle availability). Undertaking joint activities with household and/or non-household members introduces strong linkages among the activity-travel patterns of the individuals involved. Consequently, the activity-travel patterns of all household members become inter-dependent. As a result the incorporation of household interaction has received an increasing attention in travel behaviour research. Starting at the individual level, choices and tradeoffs are made between different activities, activity duration and travel time. Between individuals, interactions would directly influence these choices and tradeoffs, and indirectly influence the allocation of household resources, such as owning a vehicle. Interactions may take place in the context of the family, social groups, or an organization. However, the degree and nature of commitments within a household are different from those between different members in a social group or a certain organization. By analyzing household interactions and their impact on time allocation, a better understanding of activity and travel behaviour can be reached.

Concerned studies can be categorized into four types of approaches from a methodological viewpoint. The first approach is based on the discrete choice model system was reported by Vovsha *et al*. 2004; Bradley and Vovsha, 2005; Scott and Kanaroglou, 2002; Wen and Koppelman, 1999; Srinivasan and Bhat, 2005; and Srinivasan and Athuru, 2005. Gliebe and Koppelman (2002) who used the proportional share model of time allocation followed this approach. The second approach is based on the simultaneous equation system and was reported byGolob, 2000; Golob and McNally, 1997; Lu and Pas, 1997; Fujii et al. 1999; Meka *et al*. 2002; and Simma and Axhausen, 2001. The third approach is based on the microscopic simulation system and was reported by Meister *et al.* 2005. Finally, the fourth approach is based on the time allocation model system, and was reported by Zhang *et al*. 2003; Zhang and Fujiwara, 2006; and Zhang *et al*. 2005.

While most of previous studies examined the household interactions associated with the daily activity-travel patterns of individuals in developed countries, very few studies have dealt with inter-personal dependences in daily activity and travel behaviour of individuals in the developing countries. Therefore, not much is known about individuals’ motivations, needs, commitments, and constraints that shape the overall activity and travel patterns of individuals in developing countries. And, unfortunately, the assumption that the behavioural basis underlying household joint participation of activities and travel of individuals in developing and developed countries are similar may be not adequate. Furthermore, data from conventional activity-travel surveys often used in these studies. Conventional activity-travel surveys often do not identify the activity/travel companions explicitly, and this would requiring require the analyst to use operational definitions based on space-time matches to identify joint episodes (see for example, Gliebe and Koppelmand, 2002). Such a matching procedure, however, will not be applicable in identifying individuals’ non-household companions in activity/travel participation.

In light of these discussions, the purpose of this study is to contribute to the growing body of literature by investigating the intra-household interactions, particularly; the joint travel participation choices of individuals in developing country, and the role of culture norms, believes, social roles, mobility resources, and Internet availability in joint travel participation decisions.

This study has two motivations: <u>First</u>; from current travel behaviour and the associated household interactions in Cairo, 41.3% of all travel patterns is undertaken with companions (out of total 21 million trips around 9 million are joint trips, CREATS, 2001). Further, the results from the recent activity-travel diary survey indicate that about two-third of all weekday non-mandatory activity and 75% of all weekend non-mandatory episodes are joint. Furthermore, the empirical evidences indicate that 80% of all females travel patterns are joint travel. However, it is noted that females over the age of 6 years make 1.2 trips per person per day, compared with 2.1 trips made by males. This reflects a greater degree of gender based travel patterns and task allocation particularly for people living in Cairo. Also it reflects a significant influence of culture norms on travel behaviour and the interaction between household members. <u>Second</u>; explicit representation of joint travel decisions is important from policy implementation and practical perspective, since the level of joint participation in travel and activity patterns can strongly influence vehicle occupancy levels, trip-chaining and mode choice and thus have significant implications for congestion, air-quality, and demand estimation for transit. For instance, how a household with one car share the activities and the vehicle across household members can determine the mode choice and timing of the various trips in the household. Consequently, ignoring the impact of within-household interactions that results in joint travel and activity participation, can lead to an overly and misleading demand estimates.

Due to these motivating considerations, the objectives of this study are as follows:

1. Analyzing the intra-household interactions by modelling household members’ joint participation choice of daily travel. This objective differs from the previous studies in the following aspects:
   a) It examines explicitly intra-personal trade-offs between solo and joint travel participation decisions, and the possible substitution patterns between them.
   b) It captures the inter-personal trade-offs between solo and joint “with whom” for travel participation decisions.

2. Investigating the linkages between household Internet availability and individuals' daily joint travel participations.

In order to achieve the objectives of the study, a Mixed Multinomial Logit (MMNL) model was developed. The proposed modelling approach entails modelling the decision of household members to participate in travel as (1) solo, (2) joint with only household members, (3) joint with only non- household members, and (4) joint with combinations of household and non-household members. The modelling framework developed in this study may be distinguished from previous related studies in:

- It accommodates heterogeneity in responsiveness to solo and joint "with whom" travel participation. Therefore, intra-individual and inter-individual variations in joint travel participation could be accommodated, where as all previous studies assumed homogeneity in responsiveness to attributes of solo and joint alternatives across individuals.
- It is capable of determining the possible sources of any solo and joint preference heterogeneity that may exist.
- It could explicitly capture correlation between members of the same household and within-individuals over different travel episodes. Correlations due to shared unobservable factors among solo and joint travel participation were also analyzed.
- It is a more disaggregated model as it could capture the dependent variable at an individual-level (rather than at a role-level (head/spouse) or at a particular segment-level (male/female).
- It is capable to address intra-individual and dynamic transition in daily joint and solo travel activity participation over two-day period.

This paper is organized in Five Sections including the Introduction Section, which is followed by a description of the data sources and sample formation in Section 2. An overview of the methodology of Mixed Multinomial Logit (MMNL) modelling is presented in Section 3. Modeling results are presented and discussed in Section 4. Finally, Section 5 concludes the paper by highlighting the important findings and the proposed recommendations.

DATA SOURCES AND SAMPLE FORMATION

Data Sources

The primary data source used for this analysis is the activity-travel and telecommunication diary survey spanned the period from December 2005 to January 2006. The survey was administrated in three academic and research institutions in Cairo, Egypt. Particularly; Egyptian national institute of transportation, Ain-shams University, and the Information and Technology Institute (ITI). Respondents from the three locations were contacted first by face to face interview to solicit their participations. Respondents who agreed to participate received the relevant activity diary sheets. In addition, a comprehensive explanation for how they can infill the diary sheets was conducted. Further, they were requested to arrange for their household members above 12 years old to log their activities for two days. The response rate was some 75% (out of the 270 households to which the questionnaires were distributed).

The activity diary instrument consists of four questionnaires parts, and a core diaries part. The first two parts are concerned with various individual and household characteristics, while the third part is aimed at collecting general data about the physical activities of the respondents. The fourth part is mainly concerned with daily and non-daily Internet use and availability. The core part of the instrument consists of two diaries; the physical and Internet activities diary; and the telecommunication diary. Physical and Internet activities diary is concerned with collecting data for all in-home and out-of-home activities done by participants. For each successive activity, respondents were asked to provide information about the type of activity (based on 42 pre-coded scheme of activities), the starting and ending times of activities (beginning at 3 a.m. on the first diary sheet and ending at 3 a.m. on the second diary sheet), location of participation (respondents were asked to record the location where the activity took place based on 12 pre-coded activity locations, i.e., in-home, shopping centres, work place, school, restaurant, relative/friends house, etc.) and exact geographical location for out-of-home activities. Furthermore, for each successive activity, respondents were asked to report "with whom" they were doing this activity and "for whom" they did it. Respondents were provided with eleven pre-coded social contacts categories. These categories include the most important social networks of immediate family, relatives and friendships. The information gathered on travel episodes included information on travel mode used, transfer location, and travel time.

Respondents were also asked to complete the diaries for two consecutive days (starting either from Saturday or from Thursday, so that obtained data would cover one weekend and one weekday)[1]. After cleaning and verifying the data the final survey sample from the survey consisted of 459 respondents belong to 150 households, and contain a total of 15,935 weekday and weekend activities and travel episodes. To our knowledge, this is the first attempt to conduct an activity diary and telecommunication survey in Cairo, Egypt.

A secondary data source used in the analysis include zonal-level land-use data, transport system level of service and demographic data obtained from the Greater Cairo Transportation Master Plan Study. The secondary data provides the following information for each Traffic Analysis Zones (TAZ): (a) total number of employees and their disaggregation by sector, (b) zonal population, income and age distribution of total population, (c) the area type of the zone (CBD zone, an urban zone, a suburban zone, or a rural zone), and (d) transportation system level of service in terms of average travel, waiting, and access time for bus and transit services. This information was used to study the impact of the characteristics zone of residence on household's interaction in daily travel patterns.

Sample Formation

Several steps were pursued in extracting the final sample for analysis. First, the activity and travel data for both weekday and weekend are pooled together in one data set and then a day flag (whether it is a weekday or a weekend) is introduced as a categorical explanatory variable. Second, travel episodes were selected from the pooled activity – travel data file. In Third, all travel activity episodes were classified into 4 categories based on accompaniment type: (1) solo, (2) joint with only household members, (3) joint with only non-household members, and (4) joint with combination of household and non-household members. The participation decisions in the 4 categories constitute the dependent variable for the model developed. Fourth, data on individual, household, and zonal (zone of residence) characteristics were appropriately cleaned and added. Finally, several screening and consistency checks were performed and records with missing or inconsistent data were

[1] The weekend in Egypt is Friday and Saturday, while Sunday is a normal working day.

eliminated. The final sample considered in this analysis includes a total of 2,245 valid weekday and weekend travel episodes of 430 individuals.

MIXED LOGIT MODEL

The use of discrete choice models in transportation research has increased rapidly over the past three decades. Originally, most applications were based on the use of the Multinomial Logit (MNL) model (McFadden, 1974), which, although it has important advantages in terms of ease of estimation, it also has some certain disadvantages, notably in the form of inflexible substitution patterns. Several alternative model forms have been proposed to address these problems, with the most prominent choice being the Nested Logit (NL) model (Daly et al, 1979; McFadden, 1978; Williams, 1977), which improved flexibility by nesting similar alternatives together. Recently, the use of a more flexible form of Logit Model, the Mixed Multinomial Logit (MMNL) model, has increases dramatically. This would be attributed to improvements in the efficiency of simulation-based estimation processes, which are required when using this model form. The crucial advantages of this model over other logit-type models are: First it allows for random taste variation across decision-makers (differences across agents in their evaluation of an alternative's attributes), enabling it to give a more accurate representation of real-world behaviour than its fixed-coefficients counterparts. Second, MNL and NL models exhibit the "independence from irrelevant alternatives" (IIA) property. Because of this property, the models necessarily predict that the change in the attributes of one alternative changes the probabilities of other alternatives proportionally. This substitution pattern can be unrealistic in many settings. Third, in situations with repeated choices over time (as in our case), MNL, and NL models assume that unobserved factors are independent over time for each decision-maker. In reality, however, one would expect unobserved factors that affect a decision-maker to persist, at least somewhat, overtime. The number of applications using the MMNL model has increased steadily over the past few years, with some recent examples of applications being given by (Brownstone et al, 1999; Train, 1998; Revelt et al, 1999). For a more detailed discussion of the power and flexibility of the MMNL model, and comparisons with other model forms, see for example (McFadden et al, 2000).

In This paper, we formulate MMNL model of the decision of household members participating in travel as (1) solo, (2) joint with only household members, (3) joint with only non- household members, and (4) joint with combinations of household and non- household members. The formulation of the MMNL accommodates heterogeneity (i.e., difference in behaviour) across individuals due to both observed and unobserved attributes. Correlation in common unobserved factors influencing the choice across alternatives are also considered. It is important to note that the alternative error term correlation structure (as well as unobserved heterogeneity) in this case operates at the individual level and not at the choice occasion level. Consequently, and since the data used for the current analysis consists of multiple choice occasions from the same individual, one cannot use the cross-sectional GEV structures such as cross-nested logit. A "panel" mixed multinomial logit model is an appropriate structure that could capture the above discussed individual level heterogeneity and individual level alternative error term correlation patterns in the repeated choice data used in the current analysis.

Following (Train, 1998; Bhat, 1998), the model can be described as follows. Given that an individual i participate in travel activity, the individual i chooses among j possible solo and joint "with whom" alternatives on choice occasion t .

Let the utility $U_{i,j,t}$ that an individual i associates with an alternative j on choice occasion t be written as follows:

$$U_{ijt} = \alpha_{ij} + \beta' X_{ijt} + \varepsilon_{ijt}$$

Where α_{ij} is a scalar utility term representing individual *i*'s intrinsic preference for alternative j, β is a corresponding column vector of coefficients to be estimated for alternative j, X_{ijt} is a column vector of observed variables affecting the utility of individual i for alternative j in the choice situation t, X_{ijt} is a column vector of observed variables affecting the utility of individual i for alternative j in the choice situation t, and ε_{ijt} is a choice-occasion specific idiosyncratic random error term assumed to be identically and independently standard Gumbel distributed (across alternative choice occasions and individuals).

The accommodation for unobserved preference heterogeneity could be formulated by decomposing the scalar utility term α_{ij} in the above utility equations into two components as follows:

$$\alpha_{ij} = \alpha_0 + \gamma_i' y_j + \theta' s_p$$

Where α_0 represents the "average" (across individuals) effect of unobserved variables on the utility associated with alternative j. γ_i is a $(J \times 1)$ -column vector with its jth element capturing individual i's differential preference for alternative j compared to the "average" preference across all individuals for alternative j, and y_j is also a $(J \times 1)$ -column vector with 1 in row j and 0 elsewhere. The vector γ_i (of dimension *J*) is specified to be a *J*-dimensional realization from a multivariate normally distributed random vector γ, each of whose elements have a variance of σ_j^2. The elements of γ are assumed to be independent from each other, and the realization vector of any individual is independent of the realization vector of other individuals. The result is a variance of σ_j^2 across individuals (with no resulting covariance effects) in the utility of alternative *j*. Thus, the presence of the individual-specific γ_i vector allows unobserved heterogeneity across individuals in the intrinsic preference for each alternative that are not correlated across alternatives (*i.e.*, unobserved pure variance inter-individual heterogeneity). $\theta' s_p$ captures different preference of individuals in a certain socio-demographic group *p* across all individuals in other socio-demographic groups (*i.e.,* observed inter-individual heterogeneity). In this component, θ is a vector of coefficients, and s_p is a column vector of dimension *P* with each row representing a group *p* (*p*=1, 2…, *P*) with certain socio-demographic attributes, and takes value 1 if the *p*th element of P is unity and zero otherwise.

Next, In order to allow for correlation across the alternatives in each choice situation and indeed across choice situations, the error term ε_{ijt} may be divided into two additive (i.e. uncorrelated) parts as follows:

$$\varepsilon_{ijt} = \zeta_{ijt} + \mu_i' z_{ijt}$$

The first component ζ_{ijt} is assumed to be independently and identically standard Gumbel distributed (across alternatives and choice occasions). The second component of the error term $\mu' z_{ijt}$ induces heteroscedasticity and correlation across unobserved utility components of the alternatives at any choice occasion t. In this component, z_{ijt} is defined as a column vector of dimension *H* with each row representing a group *h* (*h*=1, 2,…,*H*) of alternatives sharing common unobserved components. The row(s) corresponding to the group(s) of which *k* is a member take(s) a value of one and other rows take a value of zero (*i.e.,* z_{ijt} =1 if *j* belongs to group *h* and 0 otherwise). The vector μ_i (of dimension *H*) could be specified as a *H*-dimensional realization from a multivariate normally distributed random vector μ, each of whose elements have a variance of ω_h^2. The result of this specification is a covariance of ω_h^2 among alternatives in group *h*, and heteroscedasticity across the group of alternatives.

Conditional on γ and μ, the probability that individual i will choose alternative j at the t th choice occasion can be written in the usual multinomial logit form:

$$P_{ijt} \setminus (\gamma, \mu) = \frac{e^{\alpha_0 + \gamma_i' y_j + \theta' s_p + \mu_i' z_{ijt}}}{\sum_j e^{\alpha_0 + \gamma_i' y_j + \theta' s_p + \mu_i' z_{ijt}}}$$

Since actual tastes are not observed, the probability of observing a certain choice is determined as an integral of the appropriate probability formula over all possible values of γ and μ weighted by its density. Therefore, the unconditional probability can be obtained as:

$$P_{ijt} = \int_{\gamma=-\infty}^{\infty} \int_{\mu=-\infty}^{\infty} \frac{e^{\alpha_0 + \gamma_i' y_j + \theta' s_p + \mu_i' z_{ijt}}}{\sum_j e^{\alpha_0 + \gamma_i' y_j + \theta' s_p + \mu_i' z_{ijt}}} dF(\mu \setminus \omega) dF(\gamma / \sigma)$$

Where *F* is a multivariate cumulative normal distribution. In order to develop the likelihood function for parameter estimation, we need the probability of each sample individual's sequence of observed choices. If *Ti* denotes the number of choice occasions observed for individual i, the likelihood function for decision maker *i* 's observed sequence of choices, conditional on γ, is:

$$L_i(\alpha, \theta, \omega, \gamma) = \prod_{t=1}^{T_i} \left[\int_{\mu=-\infty}^{\infty} \left\{ \prod_{j=1}^{J} [P_{ijt}(\alpha, \theta, \gamma, \mu)]^{N_{ijt}} \right\} f(\mu \setminus \omega) d\mu \right]$$

where *N* is a dummy variable taking the value of 1 if the *i*th individual chosses the *j*th alternative in the *t*th occasion and 0 otherwise. The unconditional likelihood function for individual *I*'s observed set of choices is:

$$L_i(\alpha, \theta, \omega, \sigma) = \int_{\gamma=-\infty}^{\gamma=\infty} L_i(\alpha, \theta, \omega, \gamma) f(\gamma \setminus \sigma) d\gamma$$

The log- likelihood function is:

$$\ell(\alpha,\theta,\omega,\sigma) = \sum_i \ln L_i(\alpha,\theta,\omega,\sigma)$$

Exact maximum likelihood estimation is not available and simulated maximum likelihood will be used instead. In this method, all parameters are estimated by drawing pseudo-random realizations from the underlying error process. The individual likelihood function is then approximated by averaging over the different $L_i(\alpha,\theta,\omega,\sigma)$ values to estimate a simulated likelihood function.

The estimated parameters are those that maximize simulated likelihood function. The bias in simulated likelihood function decreases as the number of draws increase. Simulated maximum likelihood estimation, using Halton draws, was used to estimate the parameter of the model). The number of Halton draws was set to 100. The estimations in the paper were carried out using Limdep Econometric Software version 8, Hensher et al (2005).

EMPIRICAL ANALYSIS

Variables Specifications

Several types of exogenous variables were considered as potential determinants in the analysis. These included household socio-demographic, individual socio-demographics, location and transportation level of service variables, and episode participation occasion variables. The household socio-demographic characteristics considered in the specifications include the percentage of females inside the household, percentage of high-education individuals inside the household, household size, household with Internet access at home (*i.e.,* whether the individual belongs to a household with access to the Internet, or not), and role inside the household (i.e., Head, spouse, *etc*.). The individual socio-demographics variables were explored in the specifications to include gender, age, employment status, and flexibility in work hours. The location and transportation level of service variables will include the area type variables classifying residential zones into one of four categories (CBD, urban, a suburban zone, and rural), employment density of the residential zone and the proportion of jobs in retail and services as indicators of land-use diversity. The land-use diversity variable is computed as a fraction between 0 and 1. Zones with a value closer to one on this land-use diversity variable have a richer land-use mix than zones with a value closer to zero. Different transportation level of service were specified and tested. This includes; public bus/transit average walking access time, public bus/transit average waiting time, and public bus/transit in-vehicle travel time. Episode participation occasion variables will include two types of time variables. The first is a day indicator defined by a dummy variable for weekday and weekend. The second type is the time of the day indicator, time-of-day is represented by dividing the day into three periods: morning period (3a.m.-noontime), afternoon period (noontime – 5p.m.), and evening period (5p.m. – 3a.m.).

Furthermore, to explore the association between the individuals' activity and travel patterns and the propensity for making joint trips, a group of variables representing the daily activity and travel patterns has also been used. Essentially, we have adopted two approaches; the first approach is to identify relatively homogeneous behavioural groups with observed activity engagement and time use variables using cluster analysis. This is done to reduce the great diversity in individuals' behaviour into a few reprehensive patterns of behaviour. In the second approach a group of membership indictors have been included as explanatory variables in solo and joint travel activity participation model. The clustering technique selected to identify groups of homogeneous patterns of activity and travel behaviour is the two step clustering algorithm. This technique groups objects or cases (persons) on the basis of their "nearness", which is most commonly measured by distance and similarity. Distance is a measure of how far apart two cases are, and similarity measures the closeness in two cases. In deriving the daily activity patterns the variables used are:

1. total amount of time allocated to travel in weekday and weekend (T_dur1,T_dur2),
2. total amount of time allocated to physical maintenance activity in weekday and weekend (T_ phy_main_dur1,T_phy_ main_dur2),
3. total amount of time allocated to virtual maintenance activity in weekday and weekend (T_virtu_main_dur1, T_Vitu_main_dur2),
4. total amount of time allocated to physical recreational activity in weekday and weekend (T _phy_rec_dur1, T_phy_rec_dur2),
5. total amount of time allocated to virtual recreational activity in weekday and weekend (T_virtu_rec_dur1, T_virtu_rec_dur2).

A 5-cluster solution is obtained for each of the two diary days as shown in Table 1. The first and largest cluster contains 31.69% of the sample has the longest travel time for both days (about two hours per day) and the shortest time allocated to maintenance activities in both days. Persons in this group, however, allocate a good portion of their time on physical and virtual recreational activities in both days. The second group with substantial size (23.64% of the sample) has the longest physical maintenance activities duration for both days (about six hours per day). Also, it has the second highest physical recreational duration in both two days. The third cluster with 18.74% of the sample has the longest time allocated to virtual recreational activities and the lowest time allocated to physical recreational activity in both two days. In contrast, cluster 4 of equal size (18.74% of sample) is characterized by the longest time allocated for physical recreational activity and shortest travel duration in both days. The last cluster (7.19% of the sample) has the longest time allocated to virtual maintenance activity. Persons with this pattern are also likely to allocate a longer time to virtual recreational activities. In this group physical activity durations are of "average" daily duration. This indicates that people in this group participate in many short duration activity episodes in a day.

Table 1- Average Profile of Activity Time Allocation Clusters

Variables used to create clusters		Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Cluster size (%)		31.699	23.638	18.736	18.736	7.190
Weekday	**T_dur1**	129.072	59.740	98.144	23.269	94.737
	T_phy_main_dur1 (min.)	64.710	410.677	90.464	163.462	148.947
	T_virtu_main_dur1 (min.)	0.475	0.000	0.000	0.000	100.263
	T_phy_rec_dur1 (min.)	307.661	409.844	252.113	684.038	341.842
	T_virtu_rec_dur1 (min.)	34.253	15.625	202.680	29.038	126.053
Weekend	**T_dur2**	145.929	66.488	48.200	21.712	81.277
	T_phy_main_dur2 (min.)	104.929	346.570	106.200	124.212	188.723
	T_virtu_main_dur2 (min.)	0.429	0.000	0.533	0.205	123.511
	T_phy_rec_dur2 (min.)	458.000	459.884	383.493	623.459	432.511
	T_virtu_rec_dur2 (min.)	35.429	16.364	225.067	43.288	105.957

Empirical Results

Normalization consideration and error-component specification

Table 2 provides the estimation results for the final panel MMNL model. The results for the standard logit model are presented in Table 3. The effects of all variables in the solo and joint "with whom" travel choice model are included using solo travel category as the base. Two important aspects of modelling strategy that need to be considered before estimating a MMNL model are identifying parameters with and without heterogeneity as well as the assumption regarding the distribution of each of the random coefficients. These two must be selected based on prior information, theoretical considerations, or some other criteria. Random parameters in this study are estimated as normally distributed parameters in order to allow parameters to get both negative and positive values. In the current analysis, several error components specifications were tested. However, the one that provided the best statistical results included two error components which are very specific to only joint with household members, joint with non-household members and joint with combination of household and non-household members. This result is quite intuitive, since it indicates the presence of common unobserved factors impacting joint "with whom" choices.

Overall measures of fit

The final model specification was developed through a systematic process of adding groups of different variables to the market share model (*i.e.,* the constants only model) and eliminating statistically insignificant variables. Also, variables were combined when their effects on the model were not statistically different. This process was guided by intuitive consideration and parsimony in the representation of variable effects. The log-likelihood value at convergence of the final MMNL specification is –2110.276. The log-likelihood value of the market share model is –3112.231 and the log-likelihood value of a simple multinomial logit (MNL) model is -2237.383. The likelihood ratio test value for comparing the MMNL model with the MNL model is 254.21, which is substantially greater than the critical χ^2 value with 13 degrees of freedom. Additionally, one can observe consistency in sign of coefficients across the model. All parameters of the model are statistically significant at 90% confidence level or better. The signs of all utility parameters seem to be correct and unambiguous. Furthermore, the mean coefficient of the baseline preference constants in the final MMNL model is consistently larger than the fixed coefficient in the standard logit model. This result reflects the fact that the MMNL model decomposes the unobserved portion of utility and normalizes parameter on the basis of part of the unobserved portion. Moreover, the estimated standard deviations of baseline preference constants in the MMNL are highly significant. The significant *t*-statistics for these standard deviations indicate that they are likely to be statistically different from zero, confirming that all parameters would in reality vary among population.

Unobserved Heterogeneity and Unobserved Correlation Results

As discussed in the section on modelling methodology, the model system used in this paper accommodates (a) Variations in baseline preference due to unobserved individual-specific factors, (b) Covariation in the baseline preference of different activity purposes generated by unobserved individual-specific factors, and (c) Variations in baseline preference due to observed inter-individual factors. Each of the three elements listed above will be discussed hereunder.

Table 2-MMNL Model Results for Solo and Joint "with whom" Travel Participation

Explanatory Variables	**Joint With Only Household Members**		**Joint With Only Non-Household Members**		**Joint With Combination of Household and Non-household Members**	
	Parameter	**t-statistic**	**Parameter**	**t-statistic**	**Parameter**	**t-statistic**
Joint travel preference constant	-5.282	-5.669	-3.989	-4.978	-12.860	-7.023
Standard deviation of unobserved individual heterogeneity	1.269	10.087	0.948	5.305	2.232	7.861
Heterogeneity in the Mean by						
Percentage of females inside the household	0.833	2.078				
Household with no access to Internet					-1.862	-3.555
Percentage of high education students inside the household	-1.578	-2.963			0.663	0.688
Household Socio-demographics						
Female spouse	2.123	7.730	1.319	4.494	1.965	3.986
Household size	0.375	4.623			0.662	5.526
Individual Socio-demographic and Employment Characteristics						
Young age "individual between 12 and 29 years of age"	1.445	6.172	1.076	4.581	2.852	6.389
Full time worker female x kids less than 5 years			-1.438	-2.795		
Work/study more than 8 hours a day	-0.675	-2.497				
Episode Occasion and Specific Variables						
Weekend	2.012	12.697	-0.410	-1.587	3.503	11.579
Afternoon	-0.601	-3.331			-0.506	-1.691
Car is the mode	2.363	9.479	1.240	4.294	2.300	7.733
Public bus is the mode	0.631	3.087	0.387	1.811		
Shopping purpose					1.965	3.986
Social- recreational purpose	0.973	2.756	2.114	5.928	2.586	5.795
Zonal Socio-demographics						
Employment diversity "economic activity diversity per zone"	3.212	1.987	2.987	1.894	6.302	1.927
Daily Activity and Travel Patterns						
Individual's belongs to cluster3			0.656	4.772		
Individual's belongs to cluster 4			1.295	5.410		
Individual's belongs to cluster 5			0.823	2.058		
Unobserved covariance between						
Joint travel with non-household members	-0.172	-1.673				
Joint travel with combination of household and non-household members	1.677	5.105				
Joint travel with combination of household and non-household members			-0.452	-1.746		
Log-likelihood at sample share			-3112.231			
Log-likelihood at convergence			-2110.276			

Table 3-MNL Model Results for Solo and Joint "with whom" Travel Participation

Explanatory Variables	Joint With Only Household Members		Joint With Only Non-Household Members		Joint With Combination of Household and Non-household Members	
	Parameter	**t-statistic**	**Parameter**	**t-statistic**	**Parameter**	**t-statistic**
Joint travel preference constant	-4.351	-9.039	-3.689	-7.150	-10.363	-12.178
Household Socio-demographics						
Female spouse	1.758	10.543	1.283	6.305	1.549	5.759
Household size	0.189	4.714			0.463	6.920
Individual Socio-demographic and Employment Characteristics						
Young age "individual between 12 and 29 years of age"	1.056	8.215	1.176	7.811	2.324	10.845
Full time worker female x kids less than 5 years	-1.667	-4.079				
Work/study more than 8 hours a day	-0.583	-3.971				
Episode Occasion and Specific Variables						
Weekend	1.454	10.390	-0.254	-1.416	2.641	11.531
Afternoon	-0.377	-3.477			-0.064	-0.343
Car is the mode	1.911	11.251	1.146	5.694	1.820	8.881
Public bus is the mode	0.524	3.405	0.316	1.779		
Snooping purpose					1.088	5.235
Social- recreational purpose	0.995	3.733	1.907	6.896	2.197	6.919
Zonal Socio-demographics						
Employment diversity "economic activity diversity per residential zone"	3.917	4.343	3.101	3.049	6.557	4.354
Daily Activity and Travel Patterns						
Individual's belongs to cluster3	0.504	6.211				
Individual's belongs to cluster 4	1.07	7.244				
Individual's belongs to cluster 5	0.538	2.707				
Log-likelihood at sample share	-2831.921					
Log-likelihood at convergence	-2237.383					

The unobserved pure variance inter-individual heterogeneity terms (corresponding to the $\gamma_i' y_j$ terms in the modelling methodology section) are all highly significant from a statistical standpoint (presented towards the top of Table 2). This indicates a substantial variation across individuals in the overall preference for joint travel episodes relative to solo travel episodes. In particular the highest value of the standard deviation of the joint travel with combinations of household and non- household members indicates the presence of a wide variation (across individuals) in intrinsic preference for participation in joint travel with combinations of household and non- household members.

The standard deviation of the error terms that capture correlation in individual-specific unobserved factors (corresponding to the $\mu' z_{ijt}$ terms) and affect the utility functions is shown in the last row of Table 2 (several other identifiable error component specifications to generate covariance across the baseline preferences of alternatives were also attempted, but were not statistically significant). Strong positive correlations between the joint travel with only household members and joint travel with combination of household and non-household members were found (see the last rows of Table 2). The positive sign on the estimated correlation coefficient, as obtained, indicates that unobserved factors that increase the propensity to undertake joint travel with only household members also increase the propensity to engage in joint travel with combination of household and non-household members. A plausible perspective on this result is that the individuals who desire to engage in joint travel with his household are also the ones who are more likely to undertake joint travel with combination of household and non-household members. These results suggest that common unobserved factors (including habits, life-style, and culture norms) favouring joint travel participation with only household members also favours joint travel participation with a combination of household and non-household members. Similarly, the significant negative error correlations between joint with only non-household members and joint with only household members; and joint with only non-household members and joint with combination of household and non-household members were found. This indicates substitution effects between joint travel with only household members and joint travel with non-household member's participation choices of the household members.

The effects of observed inter-individual heterogeneity (*i.e.*, the effect of explanatory variables as captured in $\theta' s_p$; see the modelling methodology section earlier) are all highly significant from a statistical standpoint. Three covariates are tested as possible sources of heterogeneity around the means of each of joint "with whom baseline preference estimates. The three covariates include the percentage of females inside the household, the percentage of high education students inside the household, and a dummy variable of household with Internet access at home (*i.e.,* whether the individual belongs to a household with access to the Internet, or not).

In developing the model, the observed heterogeneity around the mean were estimated only for joint with only household members and joint with combination of household and non-household members, as they showed the best model results. We specified that the joint with only household member's random baseline preference to be interacted with the covariates percentage of females and percentage of high education students inside the household. Percentage of high education students and household with Internet access covariates were used to estimate heterogeneity around the joint with combination of household and non-household baseline preference. As the results of the model suggests, the positive significant estimate of the mean parameter for the ("joint with only household members baseline preference" x "percentage of females inside the household") suggests that as the percentage of females inside household increases individuals belong to these households are more likely to engage in joint travel with their households members rather than engage in solo or joint with non-household members. This is an evidence of the existence of strong traditional gender role effect. The opposite pattern is observed for those belonging to households with high percentage of high education students, with a significant negative heterogeneity around the baseline preference estimate being observed for the joint with only household members constant but not for the joint with combination of household and non-household preference constant. This significant, negative parameter indicates that individuals belong to households with higher percentage of high education student are less likely to engage in joint travel with only household members. This could be attributed to their independent lifestyle. This implies that individual level of education play a large role in determining to what extent household members engage in travel together. Along similar lines, the negative heterogeneity in the baseline preference estimate of the joint travel with combination of household and non-household members with respect to household without Internet access covariate suggests the presence of strong positive effect to reduce the propensity to engage in joint travel with combinations of household members and non-household members for individuals belong to household without an Internet access. This is intuitive, and reflects that internet use have a complementary impact on household sociability out-side the home.

Variable Effects

Household Socio-demographics
Among the household socio-demographics variables (see Table2) female spouses are found to be much more likely to engage in joint travel with only household members, followed by joint travel with combinations of household members and non-household members, and on the third place joint travel with others. This may be a reflection of greater degree of task specialization by female spouses, most likely chauffeuring children; this is also a result of culture influence and traditions.

Individuals belonging to large households are more likely to pursue joint travel with combination of household and non-household members compared to individuals belonging to households with few members. This may be a reflection of the increased opportunity to socialize with others in larger households.

Individual Socio-demographic and Employment Characteristics
The effect of individuals attribute indicate that young individuals are more likely to participate in a joint travel with combination of household and non-household members compared to older individuals. This could be attributed to their active lifestyle.

Perhaps the most interesting effects found in the model are those related to interaction between the prescience of young children with full worker female. The prescience of very young children aged 6 or below, had a significant negative effect on the propensity to participate in joint travel with non-household members by full worker females. This is reasonable since joint travel with non-household members is a proxy of participating in recreational out-of home activities which could be difficult for full worker female to participate due to child care responsibility and overall time constraints.

The work and study duration has a very strong influence on choices relating to participating in joint travel with only household members during the day. The longer the individual spends at work or at school, the less he or she could participate in joint travel with household members. This result supports the hypothesis that employment separates household members for large portion of the day, making joint travel participation either more difficult to coordinate (due to time constraints) or less desirable from efficiency stand point.

Episodic Participation Occasion Variables

As expected joint travel with only household members or with combination of household and non-household members are more likely to be on weekend days than on weekdays. This result is quite reasonable, since weekend normally serves as a day for households to engage in out-of-home recreational activities.

The time of day of participation in travel episodes is an important determinant of the type of solo and joint episode chosen for participation. Specifically, individuals are less likely to participate in joint travel with only household members or with combination of household and non-household members in the afternoon than in the evening or morning. The loading of joint travel in evening may be a consequence of schedule considerations during the course of the day.

Mode of travel is found to be significant positive for both car and public bus modes; this result is intuitive, indicating that household joint travel motivation is not correlated with the transportation mode. Trips for shopping purpose have the highest propensity of being joint travel with a combination of household and non-household members. Similarly, individuals travel for social or recreational trip purposes are more likely to participate in joint travel with combination of households and non-household members, which are followed by joint travel with non-household members.

Location and Transportation Level of Service Variables

Although we tested many location and transportation level of service variables, only land-use diversity of the household residential zone is found to be significant. The diversity of economical activities of the household residential zone provides interesting results. Economical diversity has a strong positive impact on the propensity to participate in a joint travel with a combination of household and non-household members. These results may be a reflection of greater opportunities for recreational activities, and good distribution of opportunities for shopping within close proximity, in residential zones with more diverse in economical activities.

Daily Activity and Travel Patterns

Joint travel is also affected by individual daily activity and travel patterns. The direction of influence of individuals' daily time allocation to different activities and travel is intuitive. The results suggest a higher propensity to participate in joint travel with combination of household and non-household members for individuals allocate longest time for physical recreational activities for both weekdays and weekends (*i.e.,* individuals belong to cluster 4). Individuals who spend long time on virtual maintenance and recreational activities are also more likely to participate in joint travel with combination of household and non-household members. This is an interesting result which apparently supports the hypothesis that the introduction and spread of ICT, further increase household potential for social contacts with wider social network.

DISCUSSION AND CONCLUSION

The study reported in this paper provides more insights into household interactions in daily travel patterns. Further, the analysis take account of other factors that would affect the intra and inter-personal dependences associated with daily activity and travel patterns of individuals in Cairo, Egypt.

A Mixed Multinomial Logit (MMNL) model was developed using data from the recent two-day activity and travel diary survey conducted in Cairo Region, in Egypt. The proposed modelling approach entails the modelling of the decision of household members to participate in travel as (1) solo, (2) joint with only household members, (3) joint with only non- household members, and (4) joint with combinations of household and non-household members. The paper presents a panel version of the Mixed Multinomial Logit (MMNL) model that is capable of simultaneously accounting for repeated observations from the same individuals (panel), participation in multiple travel activities in two days (Multiple Discrete), and unobserved individual-specific factors affecting joint travel engagement (Mixed) including those common across pairs of joint travel category utilities.

The empirical results support many of our hypothesis regarding joint travel participations. Household traditions and believes, social roles, and lifestyle were found to be the main factors which affect joint travel. Furthermore, the results suggested additional two inter-related motivations behind joint travel namely opportunity and sociability. Opportunity refers to the ability of the household to engage in joint travel, which is strongly related to the household levels of virtual as well as physical mobility. Sociability refers to the degree of social networks between the household and the wider social world beyond the household.

The most salient findings showed that across the sampled population, the sensitivity to joint travel increases as the percentage of females inside the household increases. That is households with high percentage of females are more likely to engage in joint travel. Moreover, households with higher percentage of females are more likely to engage in joint travel with their households' members rather than engage in solo or joint with non-household members. The opposite pattern was observed for those belonging to households with high percentage of individuals with high levels of education. The results indicate that household members with high levels of education are less likely to participate in joint travel with their household due to their independent lifestyle. This implies that individual's level of education plays a large role in determining to what extent household members could engage in activity and travel together. The impact of internet availability is intuitive, the results showed that there is a strong positive correlation and taste variation in solo and joint travel participation between individuals belong to household with and those without internet availability.

Furthermore, the results suggested two significant patterns of casual relationships, namely substitution and complementary. Complementary was found between joint travel with only household members and joint travel with combination of household members and non-household members. That is as more as individuals engage in joint travel with their households they are more likely to engage in joint travel with their household members and others from their wider society. On the other hand, substitution effect was found between joint travel with only household members and joint travel with non-household members.

Overall, the results indicate substantial linkages among joint and solo travel participations patterns, household/individual characteristics and travel behaviour. These interactions need to be recognized within the framework of activity based travel modelling for accurate travel forecasting and reliable transportation policy analysis.

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