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Publication Date

1991

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Reprint
UCTC No. 40

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Reprinted from
Transportation Research Record 1236
1991, pp. 59-66

UCTC No. 40

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Recursive Model System for Trip Generation and Trip Chaining

KONSTADINOS G. GOULIAS AND RYUICHI KITAMURA

A model system is developed to describe both trip generation and trip chaining in a coherent manner. A recursive structure is adopted to represent the generation of trips for different purposes, and the number of trip chains is expressed as a function of the numbers of trips by purpose. The model system offers theoretically consistent coefficient values and quantifies the relationship between the number of trips and the number of trip chains, and can be used in the conventional forecasting procedure in place of home-based and non-home-based trip generation models. This model is applied to examine how trip chaining patterns vary across sample subgroups. The results indicate no significant variations in trip chaining behavior across car ownership subgroups. It is inferred that car ownership influences household trip generation, but given the number of trips generated, the number of trip chains is not influenced by car ownership.

The importance of trip chaining—linking of trips to visit more than one destination after leaving home—has been discussed extensively in the travel behavior literature (*1–3*). The spatial distribution of trip ends and trip timing, as well as the total number of trips, vary substantially depending on the way trips are linked to each other. Empirical evidence indicates that the destination of a non-home-based trip is heavily influenced by the location of the home base (*4*). Because consolidating trips is one of the schemes that can be used to reduce travel time and other resources expended to pursue out-of-home activities (*5*), it is likely that urban residents' trip chaining behavior will change over time as travel cost, congestion, land use patterns, and other contributing factors change.

Only limited knowledge exists on how a set of trips made by a trip-maker on a given day will be combined into trip chains. Obviously this is a complex process that involves many objectives, alternatives, and constraints. Minimizing travel distance is perhaps just one of the objectives that a trip-maker attempts to achieve. Many constraints are often not identifiable from typical home interview travel survey results, and feasible alternatives that are considered by the trip-maker are usually unknown.

The approach taken in the conventional four-step procedure is to estimate the number of home-based trips and non-home-based trips separately, then distribute the two types of trips as entirely unrelated entities. This approach unfortunately does not lead to a causal model of trip chaining behavior through which future travel patterns can be inferred under alternative scenarios, such as intensive suburban land use development, resulting in suburban congestion, or increasing gasoline prices. Several models have been proposed that describe trip chaining behavior in simplified contexts (*6–10*). Although these models draw on certain causal structures and capture salient behavioral relationships, their application to demand forecasting has been difficult because they either apply only to limited and simplified cases, or require excessive effort to generate supporting data bases.

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In this study, an attempt is made to develop a model system that describes trip generation and trip chaining at the household level. The analysis is conceived as an initial step toward a practical forecasting procedure that explicitly incorporates trip chaining. A model structure that may be termed "recursive" (*11*) is developed for the generation of trips for different purposes and formation of trip chains. The components of the model system are estimated using empirical data. Here we show the interrelationship among the number of trips by purpose and the number of trip chains, then use the model system to determine how trip chaining behavior varies across sample subgroups.

A short note is due on the use of the term, "recursive." In the terminology of simultaneous equations systems, a recursive system is that special case of structural equations that can be arranged into a system that involves only unidirectional cause-effect relations (*12,13*). Such a system presents a hierarchical, or sequential, structure in which predetermined variables determine the first endogenous variable, then the first endogenous variable and possibly other predetermined variables determine the second endogenous variable, and so on (*12*). This structure is applied in this study to trip generation by purpose and formation of trip chains.

This paper is organized as follows: The modeling approach of the study is discussed in the next section, and then the data set used is described. A set of recursive trip generation models by purpose is presented, as well as a model of trip chain generation. Also presented are the results of model application we used to examine the variation in trip chaining behavior across sample subgroups, followed by a summary of the study.

MODELING APPROACH

The concept of trip generation is an important element of the model system of this study because it links the proposed model of trip chaining to the conventional demand forecasting procedure. The introduction of the concept also reflects the viewpoint that needs to engage in activities motivate the members of a household to make a set of out-of-home stops and that trip chains are formed given the set of stops to be made.

The model system of this study adopts the structure in which the number of stops made for a given type of activities is expressed as a function of household characteristics, and these stops are then combined into trip chains. The resulting model system consists of a set of trip generation models by purpose, and a trip chaining model that translates the number of trips into the number of trip chains.

The relationship among trips made for different purposes is emphasized in the model development. It is assumed that certain trips are compulsory while others are discretionary, depending on the types of activities for which they are made. In the analysis, work and school trips are assumed to be compulsory, and personal business, shopping, and social trips are considered to be discretionary. (Trips in the latter category may not be entirely discretionary. For example, consider a grocery shopping trip that must be made to prepare a meal. However, unlike compulsory trips, a large degree of flexibility is often associated with the frequency, timing, and destination locations of these trips.)

Given this dichotomy, we assume that if these two classes of trips are interrelated at all, then the presence and number of compulsory trips influence the presence and number of discretionary trips. It is also assumed that the number of trip chains is a function of the numbers of trips by purpose. This viewpoint leads to the model structure shown in Figure 1.

A unique feature of the system of trip generation models of this study is the recursive relationship assumed among them; the number of discretionary trips is expressed as a function of the number of compulsory trips. This contrasts sharply with the conventional approach in which trips of different purposes are estimated independently without assuming any internal relationship. The approach of this study is consistent with the notion of time budget (*14*); those who expend a substantial amount of time for mandatory activities such as work and school have less discretionary time available, therefore are likely to make fewer discretionary trips. The validity of this conjecture can be statistically tested by estimating the model system.

The number of trip chains is modeled as a linear function of the number of trips by purpose. The coefficient of each trip variable in the model then indicates the average number of trip chains that is generated per trip. Estimated coefficient values point to which activities tend to be linked together with other activities into multistop chains.

For example, consider the hypothetical example in which a trip-maker makes only one one-stop chain per day that involves a work stop, that is, home-work-home. Then the number of trip chains (which equals the number of home trips) is identical to the number of work trips, and if we let

$$\text{(No. of trip chains)} = \beta_1 \text{(No. of work trips)} \quad (1)$$

then $\beta_1 = 1$. Now suppose the trip-maker makes another trip chain that involves two shopping stops, that is, home-shopping-shopping-home, in addition to the home-work-home chain. Then,

$$\text{(No. of trip chains)} = \beta_1 \text{(No. of work trips)} + \beta_2 \text{(No. of shopping trips)} \quad (2)$$

which is satisfied with $\beta_1 = 1$ as before and $\beta_2 = 0.5$. In general, trips that tend to be combined into multistop chains will have a smaller coefficient, and trips that tend to be pursued in one-stop chains will have a coefficient closer to 1 (which is the theoretical upper bound).

These coefficients also serve as indicators of the propensity to form multistop trip chains that is shared by a group of households; households that tend to consolidate trips into fewer trip chains will have smaller coefficients, whereas those that tend to make one-stop chains will have coefficients closer to 1. In the following sections, the model system is estimated and the propensity to chain trips is evaluated for household subgroups.

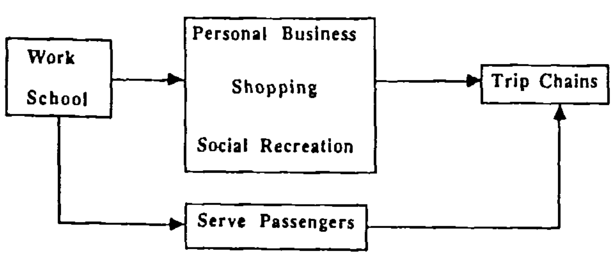

FIGURE 1 Hypothesized recursive structure involving trip generation by purpose and trip chaining.

SAMPLE FOR THE STUDY

A sample from the ongoing Dutch National Mobility Panel Survey data set is used in this study. There are two reasons for the use of this particular data set. First, weekly trip records, filled out by household members of 12 years old and over, are available from the survey. This offers reliable measures of trip generation and trip chaining that are less influenced by day-to-day variations in travel patterns. Second, use of the panel data set allows later extension of the analysis to dynamic analysis of trip chaining behavior. The analysis reported here, however, is strictly cross-sectional.

The households in the panel data set, which was intended to represent the Dutch population, were selected using a stratified sampling method based on household life cycle stage and income. The resulting sample households are scattered throughout the nation in 20 municipalities of various sizes.

Records from the first panel survey, conducted in April 1984, are used in the analysis here. All households are included in the analysis except those with missing variable values. [Discussions of the background of this panel survey and data characteristics can be found elsewhere (*14–17*).]

The set of explanatory variables used in the model development is shown in Table 1. These variables are divided into four groups. The first group consists of variables that represent household structure, which is believed to importantly influence household trip generation (*18*). In addition to the household size (HHLDSIZE), variables are included to represent the number of household members by age and sex. Also included in this group is the number of household members who filled out the weekly travel diaries (NDIARIES), which in most cases equals to the number of household members of 12 years old and over.

TABLE 1 VARIABLES USED IN MODEL FORMULATIONS

VARIABLE	DEFINITION
Household Demographics	
HHLDSIZE	Number of persons in the household
NDIARIES	Number of household members who filled out the diary
NCHILDREN	Total number of children living in the household
NCHILD:0-6	Number of children of 0 to 6 years old
NCHILD:7-11	Number of children of 7 to 11 years old
NCHILD:12-17	Number of children of 12 to 17 years old
NCHILD:18-	Number of children of 18 years old and over
NADULTS	Number of adults (> 18 years old) in the household
NMEN	Number of adult male household members
NWOMEN	Number of adult female household members
Household Socioeconomics	
NWORKERS	Number of employed persons in the household
HIEDUCATN	1 if the household member with the highest level of education has a college degree
LOEDUCATN	1 if the household member with the highest level of education have completed only elementary school
√INCOME	Square-root of annual gross household income (Dfl) divided by
√MAXPINCOME	Square-root of the annual gross income (Dfl) of the major breadwinner, divided by 100
Car Availability	
NCARS	Number of cars available to the household
ONECAR	1 if exactly one car is available to the household
TWOCARS	1 if two or more cars are available to the household
NDRIVERS	Number of licensed drivers in the household
NONDRIVERS	Number of household members (>12 years) who are not licensed to drive
Residence City Class	
LARGECITY	1 if the household resides in a large metropolitan area with highly developed multi-mode transit systems
RURALAREA	1 if the household resides in a community that is not served by rail

The variables in the second group, socioeconomic attributes, include the number of workers (NWORKERS), income measures (√INCOME and √MAXPINCOME) and levels of education (HIEDUCATN and LOEDUCATN). The use of the square root of income is based on the results of previous studies using the same data set (*17*, *19*). The education level of the household member with the highest education is used to define these education variables. Car availability is represented by the number of cars available to the household (NCARS) and two dummy variables (ONECAR and TWOCARS) to account for nonlinear effects. The number of licensed drivers and nondrivers (NDRIVERS and NONDRIVERS) is also included to represent the use of, and competition for, family cars. The two variables in the last group (LARGECITY and RURALAREA) are measures of the residence city size and an indicator of transit service levels.

TRIP GENERATION MODELS

A set of trip generation models is developed following the recursive structure of Figure 1 and using the variables shown in Table 1. Their dependent variables are the weekly total numbers of trips in the respective purpose categories reported by the diary-keepers in the household.

The general form of the models of this study is

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_k X_{ik} + \varepsilon_i = \beta' X_i + \varepsilon_i$$

where Y_i is the number of trips reported by household i, the β's are coefficients, the X's are explanatory variables, $\beta' = (\beta_0, \beta_1, \ldots, \beta_k)'$, $X_i = (1, X_{i1}, X_{i2}, \ldots, X_{ik})'$, and ε_i is a random error term. All models are estimated using weighted least squares regression, with the weight formulated as $\theta(1 + |Y_i|)^\tau$, where Y_i is the predicted number of trips for household i, and θ and τ are estimated by regressing the squared residual on the predicted number of trips.

The set of trip purpose categories used in this analysis includes: work, school, shopping, social, and serving passengers. Shopping trips include personal business, and social trips include recreational and trips for meals. Work-related business trips are not included in the analysis of this study. The results of model estimation are presented by purpose in the next section.

Work Trip-Generation Model

The weekly work trip generation model shows a good fit, explaining 56 percent of the total variation in weekly household work trip generation (Table 2). The most significant variable is the number of workers in the household (NWORKERS). The frequency of work trips is also influenced by the household size and gender composition (HHLDSIZE, NWOMEN, and NMEN).

The education and income variables (HIEDUCATN, LOEDUCATN, and √INCOME) indicate that households with higher education or higher income tend to make (or report) more work trips. These variables are multiplied by the number of workers (NWORKERS). Therefore their coefficients represent the impact of education or income on the number of work trips per worker. The city size variables (LARGECITY and RURALAREA) indicate that, other things being equal, households in large cities or in rural areas tend to generate fewer work trips.

However, the coefficients of the variables representing education, income, and residence area are statistically not significant. This model development effort indicates that work trip generation is primarily determined by the number of workers and other household demographic attributes and is not significantly influenced by education, income, and residence area, despite their likely correlation with the type of employment.

School Trip-Generation Model

The number of school trips generated by a household is determined primarily by the number of children (NCHILD:12–17 and NCHILD:18–) whose coefficients are extremely significant (Table 3). The coefficient of the number of children between 12 and 17 years old (NCHILD:12–17), who are practically all students, is very close to the number of school days in a week. Recall that household members below 12 years old were not requested to fill out the diary; otherwise the number of younger children would also have entered the model.

TABLE 2 WORK TRIP-GENERATION MODEL

Variable	β	t
NWORKERS	3.933	9.12
NWOMEN	.416	2.49
NMEN	.918	6.30
HHLDSIZE	.282	3.30
NONDRIVERS	-.457	-4.73
HIEDUCATN*NWORKERS	.234	1.14
LOEDUCATN*NWORKERS	-.349	-1.31
√INCOME*NWORKERS	.225	1.09
LARGECITY*NWORKERS	-.106	-.34
RURALAREA*NWORKERS	-.431	-1.32
Constant	-.355	
R^2	.557	
F	216.8	
df	(10,1728)	
N	1739	

β = Estimated model coefficient
t = t-statistic

TABLE 3 SCHOOL TRIP-GENERATION MODEL

Variable	β	t
NWORKERS	-.444	-6.27
NCHILD:12-17	5.378	34.16
NCHILD:18-	1.439	11.40
√INCOME*NDIARIES	.083	2.35
LOEDUCATN*NDIARIES	-.219	-4.23
HIEDUCATN*NDIARIES	.533	9.95
Constant	.566	
R^2	.546	
F	347.3	
df	(6,1732)	
N	1739	

β = Estimated model coefficient
t = t-statistic

Unlike the case of the work trip-generation model, the education and income variables have significant coefficients with anticipated signs. The education coefficients indicate that the school trip rate differs by 0.752 [0.533 − (−0.219)] trip per diary-keeper between households with the highest and lowest education levels. The significance of the education variables, however, may be in part due to the fact that the household education level may be determined by that of a child; in certain cases a higher household education level is attributed to the presence of children pursuing higher degrees. The possibility exists that the coefficients of the education variables reflect differences in trip reporting as well as actual trip making; it is likely that members of households with higher education levels tend to complete trip diaries more accurately without leaving out trips that were actually made (*16*).

Shopping Trip-Generation Model

The number of adult household members is among the significant variables that contribute to shopping trip generation (Table 4). The coefficient of the number of female adults

TABLE 4 SHOPPING TRIP-GENERATION MODEL

Variable	β	t
NWOMEN	2.376	8.57
NMEN	1.949	7.21
HHLDSIZE	.307	2.82
√INCOME*NDIARIES	.247	2.78
NONDRIVERS	-.567	-4.10
LOEDUCATN*NDIARIES	-.274	-2.35
HIEDUCATN*NDIARIES	.644	6.78
RURALAREA*NDIARIES	-.577	-3.61
Ŷ(work)	-.257	-6.71
Constant	2.066	
R^2	.281	
F	1291.6	
df	(9,1729)	
N	1739	

β = Estimated model coefficient
t = t-statistic

(NWOMEN) is substantially larger than that of the number of male adults (NMEN). The difference, which is statistically significant at $\alpha = 0.05$, indicates that an adult woman of a household tends to make 0.4 more shopping trip per week than does an adult man. The coefficient of the number of nondriving diary-keepers is negative and significant, suggesting that shopping trip generation is correlated with automotive mobility.

As anticipated, the income coefficient indicates that shopping trip generation increases with income. The coefficients of the education variables are again significant and suggest that a diary-keeper from a household with the highest education level tends to make 0.91 more shopping trip per week than does his or her counterpart from a household with the lowest education level. As in the case of work and school trips, however, this difference reflects different degrees of reporting accuracy as well as genuine differences in trip rates. This shopping trip–generation model includes the number of work trips as one of the explanatory variables. The coefficient of this variable was estimated using the predicted number of work trips obtained from the work trip–generation model as an instrument. The estimated coefficient implies negative correlation between work trip generation and shopping trip generation. This is consistent with the conjecture postulated earlier; work trip generation implies that a considerable amount of time is spent by household members for mandatory work activities, leaving less discretionary time available and leading to a lower level of discretionary trip generation. The estimated coefficient value of -0.26 suggests that approximately 1.3 less shopping trips per week will be generated by the household for each household member who is employed (the number of school trips is not included as an explanatory variable of the model because school trips are made primarily by the children of a household, who tend not to make shopping trips).

Social Trip–Generation Model

The most significant variable in the social trip generation model is the number of diary-keepers (NDIARIES). The number of children (NCHILD:12–17 and NCHILD:18-) also has a positive contribution (Table 5). The education variables (LOEDUCATN and HIEDUCATN) indicate similar effects as before. The table shows that, like shopping trip generation, social trip generation is negatively correlated with work trip generation.

The variables associated with car availability and use (ONECAR, TWOCARS, and NONDRIVERS) are all significant and indicate that social trip generation is influenced by automotive mobility. No car ownership variables were used in the work, school, and shopping trip–generation models because they were insignificant.

This significance of the car ownership variables in the social trip–generation model is presumably because social trips are least mandatory among these trip purpose categories. Generation of mandatory trips will be determined by external factors and their frequency will be independent of the relative ease of trip making. Alternatively, generation of discretionary trips is regulated by the household to a larger extent and therefore is influenced more significantly by the ease of travel and the mobility resources available to the household. The results of this study support this conjecture.

TABLE 5 SOCIAL TRIP–GENERATION MODEL

Variable	β	t
NDIARIES	2.376	8.57
NCHILD:12-17	.855	1.99
NCHILD:18-	.698	1.82
NONDRIVERS	-.785	-3.15
ONECAR*NDIARIES	.597	3.02
TWOCARS*NDIARIES	.687	2.72
LOEDUCATN*NDIARIES	-.275	-1.69
HIEDUCATN*NDIARIES	.549	4.23
RURALAREA*NDIARIES	-.131	-.59
Y(work)	-.249	-5.07
Constant	1.466	
R^2		.324
F		83.0
df		(10,1728)
N		1739

β = Estimated model coefficient
t = t-statistic

Serve-Passenger Trip–Generation Model

The structure of this trip generation model is substantially different from those of the models presented previously, as it reflects the unique nature of serve-passenger trips, that is, they are made to fulfill activity needs of other individuals, quite often other household members. Obviously very few, if at all, serve-passenger trips will be generated by households to which no automobile is available or that have no drivers. It can also be inferred that, given automobiles are available, fewer serve-passenger trips will be generated by single-person households, whereas households with nondrivers or children will on average generate more trips of this type. The model presented in Table 6 reflects these considerations.

Most of the explanatory variables in this model are mul-

TABLE 6 SERVE-PASSENGER TRIP–GENERATION MODEL

Variable	β	t
NDRIVERS*MPHH	1.21	4.73
NCHILDREN	1.24	13.51
LOEDUCATN*NDRIVERS*MPHH	-.28	-1.78
√INCOME*NDRIVERS*MPHH	-.04	-.37
Y(work)*ONECAR*MPHH	.06	1.80
Y(work)*TWOCARS*MPHH	-.15	-2.37
Y(shop+social)*ONECAR*MPHH	-.08	-4.78
Y(shop+social)*TWOCARS*MPHH	-.05	-1.68
Constant	.48	
R^2		.17
F		44.39
df		(8,1730)
N		1739

MPHH = 1 if HHLDSIZE > 1
β = Estimated model coefficient
t = t-statistic

tiplied by a dummy variable (MPHH), which takes on a value of one for multiperson households. This specification has been chosen over several alternative model specifications in which effects of the explanatory variables are not differentiated between single- and multiperson households. In addition to MPHH, the education and income variables (LOEDUCATN and √INCOME) are multiplied by the number of drivers (NDRIVERS), and predicted numbers of trips [*Y*(work) and *Y*(shop + social)] by car ownership dummy variables (ONECAR and TWOCARS).

The number of children (NCHILDREN) is highly significant and positively contributes to the number of serve-passenger trips. This result supports the conjecture that serve-passenger trips are often made for children in the household. The table also shows the anticipated result that the number of drivers (NDRIVERS*MPHH) positively contributes to the number of serve-passenger trips. As in the previous models, households with lower levels of education tend to make (or report) fewer trips in this category, but income is not significantly associated with serve-passenger trips.

The work trip instrument variable in one-car households [*Y*(work)*ONECAR*MPHH] has a positive coefficient, while that in multicar households [*Y*(work)*TWOCARS*MPHH] has a significant negative coefficient. The result suggests that fewer serve-passenger trips are made in connection with work trips by multicar households. The shopping and social trip instrument variable [*Y*(shop + social)] has a negative coefficient regardless of the car ownership level. Overall, the estimation results have shown that the number of children is the most significant variable influencing serve-passenger trip generation.

TRIP CHAIN MODEL

The trip chain model of this study represents the relationship between the number of trips by purpose and the number of trip chains made by household members. The model, shown in Table 7, is simple, consisting of three instrument variables [*Y*(work), *Y*(school), and *Y*(shop + social)]. No constant term is included because no trip chains can be made when no trips are made.

The coefficients of the trip generation instrument variables are measures of how trips of the respective categories are formed into trip chains. The coefficient of *Y*(work), 0.897, implies that a work trip on average generates 0.897 trip chain. The smaller coefficient (0.800) of *Y*(school), on the other hand, suggests that school trips are linked to other trips into multistop chains more frequently. The coefficient of *Y*(shop + social), which is very close to one, suggests that practically all trips of this category are made in one-stop chains.

TABLE 7 TRIP CHAIN MODEL

Variable	β	t
Y(work)	.897	15.15
Y(school)	.800	10.49
Y(shop+social)	.994	32.76
R^2	.887	
F	4560.9	
df	(3,1736)	
N	1739	

β = Estimated model coefficient
t = t-statistic

The theoretical upper bound of these coefficients is 1.0, because a trip cannot generate more than one trip chain. The estimation result is logical with none of the coefficient estimates exceeding this theoretical maximum, and all coefficients are positive and significant.

This trip chain model is now used to examine possible variations in trip chaining behavior across sample subgroups. The focus of the analysis is on the tendency in consolidating trips for various purposes into trip chains, and how the tendency varies across subgroups. Subgroups defined in terms of income, car ownership, and city size are examined in the analysis. The results are summarized in Table 8 in terms of the estimated coefficients for the respective subgroups. Also presented in the table are *F*-statistics to test the significance of the variation in the coefficient values across the subgroups.

The *F*-statistics indicate that the coefficient vectors are significantly different across income subgroups and city-size subgroups. The coefficients of the three income subgroups indicate that the high-income group tends to make work trips and discretionary (shopping and social) trips in multistop chains more frequently, and school trips by themselves in single-stop chains. No differences are appreciable in the coefficient estimates between the low and medium income subgroups.

The result that high-income households tend to consolidate work and discretionary trips into multistop chains is consistent with previous findings (*3*). However, this tendency does not uniformly apply to all trip purposes. The result of this analysis implies that patterns of trip chaining must be examined by trip purpose.

The coefficients of the trip chain models are also significantly different across the city-size subgroups. The estimation results indicate that residents of large cities tend to make discretionary trips in multistop chains. The coefficients of the work trip instrument are stable across the subgroups, whereas those of the school trip instrument suggest that school trips are linked to others more often in both small and large urban areas.

The coefficient of the school trip instrument is extremely small for the no-car subgroup. This, however, did not lead to a significant *F*-statistic for the car ownership subgroups. In fact all of the other coefficients are within 8 percent of the coefficient estimates for the entire sample shown in Table 7. This result suggests that trip chaining behavior may not be as much influenced by car ownership as it has been believed to be; the effects of car ownership on trip chaining observed previously may have been caused by the effect of car ownership on trip generation rather than on trip chaining. The validity of this conjecture must be tested in further investigation.

The estimated coefficient values shown in Table 8 are again theoretically supportable, lying between 0 and 1 for most cases. A few estimates are above the upper bound of 1.0, but only by small amounts, and in no cases do they exceed the bound with statistical significance. This consistency in the coefficient estimates is extremely encouraging, especially in

TABLE 8 TRIP CHAIN MODELS BY INCOME, CITY SIZE, AND CAR OWNERSHIP SUBGROUPS

Income	Low (≥$21,000)		Middle		High (≤$37,000)		
Variable	β	t	β	t	β	t	Difference
Y(work)	1.027	8.73	1.076	8.84	.861	8.11	
Y(school)	.736	6.64	.770	5.48	1.060	6.53	
Y(shop+social)	.997	25.39	.984	15.85	.900	12.99	
R^2	.857		.888		.906		
F	1396.8		1465.7		1547.3		3.081*
df	(3,697)		(3,553)		(3,480)		(6,1730)
N	700		556		483		1739

City Size	Small		Medium		Large		
Variable	β	t	β	t	β	t	Difference
Y(work)	.879	2.88	.902	13.86	.858	6.07	
Y(school)	.626	1.78	.802	9.66	.665	3.14	
Y(shop+social)	1.092	6.35	1.004	30.31	.839	11.82	
R^2	.857		.891		.886		
F	234.5		3924.7		457.0		3.246*
df	(3,117)		(3,1437)		(3,176)		(6,1730)
N	120		1440		179		1739

Car Ownership	No Car		One Car		Two Cars		
Variable	β	t	β	t	β	t	Difference
Y(work)	.885	7.99	.862	10.76	.933	5.15	
Y(school)	.393	2.48	.864	8.96	.758	3.07	
Y(shop+social)	.982	21.39	1.011	25.06	.978	8.42	
R^2	.821		.889		.918		
F	690.3		1465.7		737.4		1.582
df	(3,452)		(3,1080)		(3,198)		(6,1730)
N	455		1083		201		1739

β = Estimated model coefficient
t = t-statistic
Note: None of the estimated coefficients β is significantly larger than the theoretical upper bound of 1.0.
* Significant at $\alpha=0.05$.

light of the small sample sizes of some of the subgroups. The study results also offer an encouraging indication that this simple trip chain model can be used to examine the characteristics of trip chaining behavior by population subgroups.

CONCLUSION

An attempt has been made in this study to develop a model system that describes both trip generation and trip chaining in a coherent manner. The model system adopts a recursive structure in representing the generation of trips for different purposes. The number of trip chains is expressed as a function of the numbers of trips by purpose. The estimated coefficients of the recursive models have indicated the presence of negative correlation between mandatory and discretionary trips, suggesting the influence of time budgets. The trip chain model has offered theoretically consistent coefficient values and quantified the relationship between the number of trips by purpose and the number of trip chains. This model has been applied to examine how trip chaining behavior varies across sample subgroups. The results indicate that variations in trip chaining exist among income subgroups and city-size subgroups, but not among car ownership subgroups.

The finding that higher income households tend to consolidate trips into multistop chains is consistent with earlier findings. However, the analysis of this study has shown that not all trips are consolidated at the same rate; it has been shown that school trips are combined with other trips less frequently by the high-income group. Such associations between trip chaining and trip purposes must be properly reflected in models of trip chaining behavior.

No significant variations in trip chaining behavior have been found across car ownership subgroups in this study. An important conjecture stems from this: Car ownership influences household trip generation, but given the number of trips generated, the number of trip chains is not influenced by car ownership. This conjecture is worthy of further examination in the future.

This study has shown that a model system can be successfully developed integrating trip generation and trip chaining. The theoretically supportable coefficient estimates of the trip chain model are extremely encouraging. The proposed model system can be incorporated almost immediately into the conventional travel-demand forecasting procedure. The trip generation models indicate the total number of trips made by trip purpose, including both home-based and non–home-based trips. A procedure can be developed to classify a predicted number of trips into these two types based on the coefficients of the trip chain model. The model system will then offer the same forecasts as does the conventional set of home-based and non–home-based trip generation models, in a logically coherent manner. However, the model system presented here is in its initial stage of development. Its validation and careful refinement remain as a future task.

ACKNOWLEDGMENTS

This research was supported by a National Science Foundation grant to the University of California at Davis. The data set used was obtained from the Dutch National Mobility Panel Survey results. The survey was sponsored by the Projectbureau for Integrated Traffic and Transportation Studies and the Directorate General of Transport, Dutch Ministry of Transport and Public Works.

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Publication of this paper sponsored by Committee on Traveler Behavior and Values.