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Publication Date

1990

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Reprint No. 62

The University of California Transportation Center

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Reprint No. 62

Transportation Research Record
No. 1285, 1991

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Practical Method for the Estimation of Trip Generation and Trip Chaining

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A model system of trip generation and trip chaining was developed by integrating concepts from activity-based analysis. The structure of the model system is recursive, depicting a sequential decision-making mechanism. The results were based on a data set from the Detroit metropolitan area. They were compared with those of a previous study that used a data set from the Netherlands. Differences were observed not only in the values of the regression parameters estimated but also in the decision mechanism inferred.

Trip generation is the first step of the conventional sequential forecasting procedure (*1*). The subsequent steps are based on estimates derived from trip generation analysis. Hence, the validity of the assumptions on which trip generation analysis is based and the accuracy of the trip generation models are major determinants of the overall quality of the forecast.

The conventional approach in trip generation is to estimate the number of home-based trips and non-home-based trips using separately formulated models. This approach, however, may not properly reflect behavioral relationships for several reasons. The implicit assumption that home-based and non-home-based trips are mutually independent is particularly dubious. The activities pursued at each trip destination may be related, resulting in dependence among the trips made. An approach that accounts for dependence among trips would be consistent with the notion of time budget (*2–4*). A more realistic depiction of the trip generation process is desired for improved predictive accuracy of trip generation models. Another issue related to travel behavior is the effect of unobserved constraints (e.g., unavailability of transit, restrictive store hours, etc.) on trip generation. A comparison of trip generation models obtained from areas of different characteristics would yield useful insights into constrained travel behavior.

In this study, concepts from activity-based analysis are combined with the concept of trip chaining to formulate a model system that links trip generation and trip chaining ("trip chaining" refers to the linking of trips, and "trip chain" is defined in this study as a series of linked trips that starts and ends at a home base). The model system accounts for interactions among various activities and provides trip generation rates by purpose as its outcome. The number of trip chains is expressed as a function of the trip frequencies by activity type. It is then shown that the model system can be applied to determine conventional home-based and non-home-based trip generation rates. Model systems are estimated using two data sets, one from the Netherlands and the other from the Detroit metropolitan area, to examine the nature of trip generation and trip chaining behavior in the two areas of substantially different land use and transportation network developments. The analytical method of this study draws on results obtained in a previous effort (*5*).

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BACKGROUND

A relatively new but well-established approach in travel behavior analysis is activity-based analysis [see Jones et al. (*6*) and Kitamura (*7*) for a review of past research]. The key concept behind the activity approach is that the travel patterns of households are a consequence of the more general structure of activities of the household members. It is explicitly recognized that trip making is a means of satisfying the need to pursue activities. The activity-based approach recognizes that decisions made by households to engage in different activities are correlated (*8*). Also considered in this approach is the presence of time and space constraints (*9,10*) under which a household makes travel decisions.

The linking of activities that leads to the linking of trips has motivated the trip chaining approach (*11–13*). The advantage of the trip chaining approach is that it offers a framework for rigorous investigation of possible interrelationships among travel characteristics. Thus the relationship among different types of activities pursued, time spent on these activities, and the characteristics of trips made for them can be coherently studied. Unfortunately, these concepts have not been widely applied (*12,14*). This study, which extends the results presented earlier (*5*), bridges the gap between theory and practice by adopting a simplified representation of the decision mechanism underlying trip generation and trip chaining.

FORMULATION OF THE MODEL SYSTEM

The trip generation models of the proposed model system are divided into two categories. The first includes trips made by a household to pursue mandatory activities, for example, work and school. The second includes trips made to engage in activities that can be considered discretionary. "Discretionary" is defined broadly: an activity is discretionary if decisions for engagement, location, timing, and duration involve flexibility. Trips made to pursue these activities are assumed to be more flexible. The focus of this paper is on the frequency of trips; direct analysis of the duration, location, and timing of activities is outside its scope.

Assuming that the number of discretionary trips is dependent on the number of mandatory trips, the formulation allows for one-way dependence among trip purposes. Given the mandatory trips made to work and school, households determine the number of trips for other purposes and eventually combine their trips (see Figure 1). This formulation is consistent with the hierarchical subdivision of activities (7) and the notion of time budget (2–4).

Given this conceptualization, the decision mechanism for household trip generation can be formulated by using a triangular or recursive structure that represents the hierarchical decision process outlined. The salient characteristic of this triangular system is that predetermined variables define the first set of endogenous variables, which, combined with exogenous variables, in turn define the second set of endogenous variables, and so on. The number of trips for mandatory activities can be expressed as a linear function of exogenous variables alone (e.g., income and structure of the household). The number of trips for discretionary activities may be represented by a linear function of the number of mandatory trips as well as exogenous variables. The statistical significance of each variable can be used to identify possible causal links between exogenous and endogenous variables. For example, a significant coefficient obtained by regressing the number of trips made for personal business on the number of trips made for work indicates that the household decision regarding the number of trips made for personal business is dependent on the number of trips made for work. Finally, the number of trip chains is formulated as a linear function of the number of trips by purpose.

The formulation of the model system is as follows. Let the general form of the model of the number of mandatory trips be

$$Y_i^m = \alpha_0^m + \alpha_1^m X_{i1} + \alpha_2^m X_{i2} + \ldots + \alpha_k^m X_{ik} + \varepsilon_i \qquad (1)$$

where

Y_i^m = number of trips made by household i for mandatory purpose m,

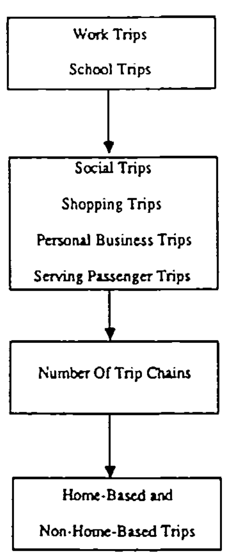

FIGURE 1 Model system.

X_{ij} = jth exogenous variable for household i,
α_j^m = the associated coefficient, and
ε_i = a random error term.

The form of the model for the number of discretionary trips is specified in a similar manner, using the number of mandatory trips as exogenous variables that are determined in the first tier of the model system. The model can be written as

$$Y_i^d = \beta_0^d + \beta_1^d X_{i1} + \ldots + \beta_j^d X_{ij} + \sum \theta_m^d Y_i^m + \xi_i \qquad (2)$$

where

Y_i^d = number of trips made by household i for discretionary purpose d,
$\beta_0^d, \ldots, \beta_j^d$ = coefficients,
θ_m^d = the coefficient associated with the endogenous variable Y_i^m,
ξ_i = a random error term.

and X_{ij} is as defined earlier.

The number of trip chains is modeled as

$$Z_i = \delta_1 Y_i^1 + \delta_2 Y_i^2 + \ldots + \delta_n Y_i^n + \nu_i \qquad (3)$$

where

Z_i = number of trip chains made by household i,
Y_i^n = number of trips for purpose n (both mandatory and discretionary) for household i, and
ν_i = a random error term.

The coefficients δ_j theoretically take on values between 0 and 1. They indicate the propensity of households to link trips. A higher value of a coefficient indicates a lower likelihood that trips for the particular purpose are linked in a multistop chain (a sequence of trips that includes more than one stop during the home-to-home tour) (5).

The estimated number of trip chains is

$$\hat{Z}_i = \hat{\delta}_1 \hat{Y}_i^1 + \hat{\delta}_2 \hat{Y}_i^2 + \ldots + \hat{\delta}_n \hat{Y}_i^n = \hat{\boldsymbol{\delta}}'\hat{\mathbf{Y}}_i \qquad (4)$$

where

$\hat{\boldsymbol{\delta}}'$ = vector of the estimated coefficients,
$\hat{Y}_i^j$ = estimate of the number of trips for purpose j, and
$\hat{\mathbf{Y}}_i$ = a vector of the $\hat{Y}_i^j$.

$\hat{Y}_i^j$ is expressed for mandatory trip purposes as

$$\hat{Y}_i^m = \hat{\alpha}_0^m + \hat{\alpha}_1^m X_{i1} + \hat{\alpha}_2^m X_{i2} + \ldots + \hat{\alpha}_k^m X_{ik} \qquad (5)$$

and for discretionary trip purposes as

$$\hat{Y}_i^d = \hat{\beta}_0^d + \hat{\beta}_1^d X_{i1} + \hat{\beta}_2^d X_{i2} + \ldots + \hat{\beta}_j^d X_{ij} + \sum \hat{\theta}^m \hat{Y}_i^m \qquad (6)$$

The conversion of the number of trip chains into home-based and non-home-based trip rates is based on simple identities. For household i, the expected number of home-based trips is

$$(\text{HB trips})_i = 2\,\hat{Z}_i \qquad (7)$$

and the expected number of non-home-based trips is

$$(\text{NHB trips})_i = \sum \hat{Y}_i^n - (\text{HB trips})_i \quad (8)$$

where n indicates a mandatory or discretionary trip.

Now, let the sample mean of $\hat{Z}_i$ be

$$\overline{Z} = \sum \hat{Z}_i / N \quad (9)$$

where N is the sample size, and let the estimated mean number of trips for purpose n be

$$\overline{Y}(n) = \sum \hat{Y}_i^n / N \quad (10)$$

The average number of home-based trips per household is given by

$$\text{HB trips} = 2\,\overline{Z} \quad (11)$$

and the average number of non-home-based trips per household is given by

$$\text{NHB trips} = [\overline{Y}(1) + \overline{Y}(2) + \ldots + \overline{Y}(n)] - \text{HB trips} \quad (12)$$

ESTIMATION OF THE MODEL SYSTEM

The estimation procedure followed the same methodology as the previous study (*5*). Trip generation models by purpose were estimated first. Alternative specifications were defined and tested for significance of the included regressors. Subsequently, a trip chaining model was obtained using the expected trip generation rates by purpose as explanatory variables. Home-based and non-home-based trip rates were then obtained through Equations 11 and 12 using the predictions from these models.

Sample

A sample from the 1980 Southeastern Michigan Transportation Authority survey was used in the estimation. The data file contains the demographic and socioeconomic attributes of 2,285 sample households. In addition, records of all trips made by household members age 5 or over by all modes of travel (motorized as well as nonmotorized) are included.

The household was chosen as the unit of analysis for several reasons. First, from the viewpoint that the household is a decision unit where resources are pooled, tasks assigned, and activities jointly pursued, it is a logical unit of analysis. Moreover, trip generation at the household level is much less variable than at the personal level, leading to smaller standard errors in parameter estimates. In addition, in the previous study (*5*) the unit of analysis was the household; to compare the results the household was used in this study also.

The explanatory variables used in the model system are shown in Table 1. The variables are grouped into six categories. The first group consists of variables that describe the household structure—household size, number of children by age group, number of adults, and number of adult males and females. The second group includes variables that describe the stage in the household life cycle. The third group consists of variables describing the characteristics of the head of the household, such as gender and age. The latter is represented by a set of dummy variables to account for possible nonlinearities. The economic status of the household is described by variables in the fourth category. The fifth category is made up of variables describing the intensity of land use and residential location. The notion that trip generation is invariant across different types of areas has been shown to be inappropriate (*15*). The sixth category is made up of variables that represent the availability of cars to household members. Unlike the Dutch data set used in the earlier study (*5*), no informtion on employment and education levels of the household members was included. The variable for employment in the original data file was excluded due to its poor quality, and no variable was available for education. It is expected that other variables will function as surrogates for them. For example, it is well known that income of a household is strongly correlated with the employment and education levels of its members (*16*).

Trip Purposes

The definition of trip purposes is based on the activity engaged in at the trip end. The trip purpose categories in the original data file were grouped in this paper into work, school, shopping, social, personal business, and serving passengers. Social trips include trips made for recreation, social visits, and other social activities. Personal business includes non-work-related personal business trips, medical trips, eat-meal trips, and other unclassified trips.

Estimation Results

All the regression models were estimated using a generalized least-squares procedure with weights as described in the previous study (*5*). The weights were defined as functions of the theoretical variance of the dependent variable to account for heteroskedasticity (variation of the variance of the error term across observational units). For regression models that involve the numbers of trips for other purposes as explanatory variables, the estimates obtained from the models in the earlier tiers were used as instruments to obtain consistent coefficient estimates. See Johnston (*17*) for a detailed discussion.

The estimated trip generation models are shown in Tables 2 to 8. The presence of possible multicollinearity was measured through the use of the tolerance value. This is defined as $1 - R_j^2$, where R_j^2 is the multiple coefficient of determination obtained when the jth variable is regressed against the other independent variables in the model. Hence, a high value of tolerance implies small multicollinearity, and vice versa. A description of each model follows.

Work Model

The daily household work trip generation model is shown in Table 2. It explains 31 percent of the total variation in the

TABLE 1 VARIABLES USED IN MODEL FORMULATION

VARIABLE	DEFINITION
Household Demographics	
HHLDSIZE	Number of persons in the household
NADULTS	Number of adults in the household
NCHLD:0-4*	Number of children 0-4 years old
NCHLD:5-15	Number of children 5-15 years old
NCHLD:16-18	Number of children 16-18 years old
NMALES	Number of adult males
NFEMALES	Number of adult females
Household Lifecycle Stage	
NOCHLD-YNG	1 if head of household less than 35 years of age and no children in the household less than 18 years of age
NOCHLD-MID	1 if head of household greater than 35 years of age but less than 65 years of age and no children in the household less than 18 years of age
NOCHLD-OLD	1 if head of household geater than 65 years of age, and no children in the household less than 18 years of age
PRESCHOOL	1 if the youngest child in the household is less than 6 years of age for head of household of any age
SCHOOLAGE*	1 if the youngest child in the household is 6 years of age or older for head of household of any age
Household Head Characteristics	
HDMALE	1 if head of household is male
HDFEMALE	1 if head of household is female
HDAGE:16*	1 if age of head of household is less than 16 years
HDAGE:16-30	1 if age of head of household is between 16 and 30 years
HDAGE:31-50	1 if age of head of household is between 31 and 50 years
HDAGE:51-64	1 if age of head of household is between 51 and 64 years
HDAGE:65	1 if age of head of household is greater than 65 years
Household Income	
LOW*	1 if annual household income is less than $10,000
MID-LOW	1 if annual household income is between $10,000 and $20,999
MID-HIGH	1 if annual household income is between $21,000 and $34,999
HIGH	1 if annual household income is $35,000 or more
Residence County and Area Type	
DETROIT	1 if residence zone is in Detroit
WAYNE	1 if residence zone is in Wayne County
OAKLAND	1 if residence zone is in Oakland County
MACOMB	1 if residence zone is in Macomb County
WASHTENAW	1 if residence zone is in Washtenaw County
MONROE	1 if residence zone is in Monroe County
STCLAIR	1 if residence zone is in St. Clair County
LIVINGSTON*	1 if residence zone is in Livingston County
COMMERCIAL	1 if 10 or more employees per acre of usable land
HIDENSITY	1 if less than 10 employees and more than 5 dwelling units per acre of usable land
MIDDENSITY	1 if less than 10 employees and from 0.5 to 5 dwelling units per acre of usable land
LOWDENSITY*	1 if less than 10 employees and less than 0.5 dwelling units per acre of usable land
Car Availability and Ownership	
NLICENSE	Number of licensed drivers in the household
NCARS	Number of cars owned by a household
ALWAYS	1 if the number of cars is greater than or equal to the number of licensed drivers in the household
SOMETIMES	1 if there is at least one car and one driver in the household and the number of cars is less than the number of drivers
NEVER*	1 if no car is available to the household

*omitted dummy variable

TABLE 2 WORK TRIP GENERATION MODEL (NUMBER OF WORK TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
NADULTS	0.2210	5.14	0.4583
NLICENSE	0.2009	4.50	0.3010
NCARS	0.1267	3.68	0.4296
NOCHLD-OLD	-0.4601	4.25	0.9400
HDAGE:31-50	0.2194	3.79	0.9042
MID-LOW	0.2909	3.90	0.6004
MID-HIGH	0.6809	7.96	0.4629
HIGH	1.1062	10.37	0.4929
OAKLAND	0.2238	3.25	0.9102
Constant	-0.3235		

R^2	0.3125
F	114.92
df	(9,2275)
N	2285

β = Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables

TABLE 3 SCHOOL TRIP GENERATION MODEL (NUMBER OF SCHOOL TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
NADULTS	0.2625	12.50	0.9702
NCHLD:16-18	1.0514	18.40	0.9205
NCHLD:5-15	0.8372	36.46	0.8122
PRESCHOOL	-0.1989	3.74	0.8324
HDAGE:16-30	0.2601	5.00	0.6701
HDAGE:31-50	0.1152	2.41	0.6693
WASHTENAW	0.5549	6.69	0.9731
Constant	-0.2415		

R^2	0.5453
F	341.149
df	(7,2277)
N	2285

β = Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables

TABLE 4 SHOPPING TRIP GENERATION MODEL (NUMBER OF SHOPPING TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
HHLDSIZE	0.1720	8.15	0.6073
NFEMALES	0.1334	2.84	0.7878
NOCHLD-YNG	0.1059	1.79*	0.7909
ALWAYS	0.1773	2.92	0.6399
SOMETIMES	0.1420	1.77*	0.6196
HIGH	0.1259	1.60*	0.9295
MACOMB	0.3154	3.64	0.9654
Constant	-0.0598		

R^2	0.0787
F	27.80
df	(7,2277)
N	2285

β = Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the multiple R-square obtained when the jth variable is regressed on the other independent variables
* not significant at $\alpha = 0.05$

TABLE 5 SOCIAL TRIP GENERATION MODEL (NUMBER OF SOCIAL TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
HHLDSIZE	0.0786	3.29	0.3922
NCHLD:5-15	0.1458	3.46	0.5495
NLICENSE	0.1486	5.77	0.5938
NOCHLD-MID	-0.1289	-2.94	0.9154
WAYNE	-0.1128	-2.32	0.9817
STCLAIR	0.2660	1.77*	0.9873
Constant	0.0847		

R^2	0.0869
F	36.15
df	(6,2278)
N	2285

β = Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the multiple R-square obtained when the jth variable is regressed on the other independent variables
* not significant at $\alpha = 0.05$

TABLE 6 PERSONAL BUSINESS TRIP GENERATION MODEL (NUMBER OF PERSONAL BUSINESS TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
HHLDSIZE	0.1537	5.86	0.5159
HDMALE	-0.1607	-2.84	0.9791
PRESCHOOL	-0.3612	-4.35	0.7388
WASHTENAW	0.3865	2.70	0.9914
HIDENSITY	-0.1535	-2.42	0.9331
Y(Work)	0.3845	8.49	0.6226
Constant	0.2423		

R^2	0.1142
F	48.94
df	(6,2278)
N	2285

β= Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables

TABLE 7 SERVE-PASSENGER TRIP GENERATION MODEL (NUMBER OF SERVE-PASSENGER TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
MPHH*ADULTS	-0.0014	-0.09*	0.3069
MPHH*NCHLD:16-18	0.1338	1.42*	0.9750
MPHH*NCHLD:5-15	0.1139	3.93	0.9451
MPHH*NLICENSE	0.0494	1.96	0.1992
MPHH*HDMALE	-0.0667	-2.23	0.6697
MPHH*Y(Work)	0.0940	2.64	0.2156
Constant	0.0324		

R^2	0.0500
F	15.00
df	(6,2278)
N	2285

β= Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables
MPHH = 1 if HHLDSIZE > 1.
* not significant at $\alpha = 0.05$

TABLE 8 TRIP CHAIN MODEL (NUMBER OF TRIP CHAINS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
Y(Work)	0.4130	3.99	0.0567
Y(School)	0.9684	13.89	0.1833
Y(Shop)	0.5146	2.54	0.0419
Y(Social)	1.1300	4.16	0.0374
Y(Personal Business)	0.5687	2.78	0.0243
R^2	0.7970		
F	1790.77		
df	(5,2280)		
N	2285		

β = Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables

number of work trips per day. The number of work trips was strongly associated with the income level. Income may function as a surrogate for the education and employment levels of the household members, which, as mentioned earlier, were not adequately represented by the variables available in the data base.

The number of work trips increased with increasing number of adults, cars, and licensed drivers in the household. It decreased when the head of the household was aged (more than 65) and had no children, presumably indicating the effect of retirement on work trip generation.

The presence of a variable indicating the county of residence (Oakland) indicates that other factors that influence work trip generation are captured in this dummy variable. This variable could be interpreted as representing the average unmeasured characteristics of households residing in that area relative to those of the counties represented by the omitted dummy variables.

School Model

The school trip generation model is shown in Table 3. As expected, the primary determinant of the number of school trips was the number of children in a household. Elder children (16 through 18) contributed more than their younger counterparts (5 through 15). The result agreed with the previous results from weekly trip generation models estimated on a Dutch data set (5). Children in both age groups are almost entirely students, and this was reflected in the magnitude of the coefficients (0.8372 for age group 5–15 and 1.0514 for age group 16–18), indicating that they were each making approximately one school trip per day.

However, the number of adults was another important determinant because of the presence of adult students in the household. The dummy variable associated with Washtenaw County presented a positive and significant effect, presumably because of the large universities present in that jurisdiction. The age group of the head of the household with a maximum contribution to school trip generation was 16–30, suggesting that the school trips were made by either the head of the household or the household head's young children. The dummy variable for this group (HDAGE: 16–30) and the one for the households with preschool children with the negative coefficient appear to separate households of adult students from families.

Shopping Model

Table 4 shows the shopping trip generation model. Household size contributed the most. Trips also increased with income and car availability. The coefficient of the number of adult females in a household implies that they make more shopping trips than adult males. As in the school trips, some difference by county of residence was indicated.

Social Model

Quite notable is the result that the number of licensed drivers in the household contributed most to social trip generation (Table 5). Household size and the number of children aged 5 to 15 were the other two important variables with positive influence. Fewer social trips were generated when there were no children in the household and the head was 35 to 65. Again, variations across county of residence were indicated by the model.

In the beginning of the study, it was anticipated that shopping and social trips would be discretionary and thus influenced by mandatory trip generation. However, estimation results indicated that shopping and social trips were not significantly influenced by work and school trips. This result contradicted the previous findings (5), in which a trade-off between mandatory and discretionary trip generation was evident. Apparently the indication obtained in this study does not support the notion of travel time budget, namely, that if household members spend more time on mandatory activities, they are left with less time to pursue discretionary activities and therefore make fewer discretionary trips. However, if time-space constraints are less restrictive (for example, if store hours extend well beyond work hours) trip generation for shopping and recreational activities may not be influenced by mandatory trips. The validity of this conjecture must be determined by further investigation of time expenditure patterns and spatial distribution of activity locations.

Personal Business Model

Two trip generation models in which the number of work trips was significant were those for personal business and serving passengers (Tables 6 and 7). Household size was one of the most significant variables and contributed positively to the number of personal business trips generated. The household's life cycle entered the model through the dummy variable for households with preschool children. The instrument variable for work trips was the most significant, contributed positively, and indicates that, other factors being equal, a household on the average generates one personal business trip for every three work trips.

Serve-Passenger Model

The peculiarity of this trip purpose was clearly reflected by the model structure (Table 7). During the model development process, in which a variety of model formulations were estimated, it was found that single-person households generate a negligibly small number of serve-passenger trips. Thus the model in Table 7 contains variables that are defined exclusively for households with two or more persons. The same approach was used in the previous model formulation (*5*). Serve-passenger trips were positively influenced by the number of children and the number of licensed drivers. All these indications are as expected. The work trip instrument variable positively influenced the number of serve-passenger trips and indicates that 1 serve-passenger trip is generated for every 10 work trips, on the average.

Trip Chain Model

The trip chain model is shown in Table 8. It consists of five instrument variables, Y(work), Y(school), Y(social), Y(shop), and Y(personal business). The number of trip chains is equivalent to the number of home trips (trips made with home as the destination). The largest theoretical value of these coefficients is 1 (one trip cannot generate more than one trip chain). All the coefficients in the model are consistent with this requirement except the one for social trips, although the coefficient is not significantly greater than unity.

If a coefficient is closer to 1, it indicates a lower propensity to link trips for that trip purpose with other trips. The estimated coefficients showed that work, shopping, and personal business were more likely to be linked in a multistop chain, whereas social and school activities tended to be pursued in a single-stop chain. In the short term the coefficients associated with each trip purpose can be used to estimate the relative effect of changes in trip generation on the formation of trip chains. For example, if a household makes one more shopping trip, the number of trip chains is likely to increase by slightly more than 0.5.

Estimation of Home-Based and Non-Home-Based Trip Generation

By using Equations 4 and 6 and the model presented in Table 8, the estimated number of trip chains for this sample was obtained as

$$\hat{Z} = 0.4130\ \hat{Y}(\text{work}) + 0.9684\ \hat{Y}(\text{school}) + 0.5146\ \hat{Y}(\text{shop}) + 1.1300\ \hat{Y}(\text{social}) + 0.5687\ \hat{Y}(\text{personal business})$$

whose sample average was 2.87. From Equation 11 the total number of home-based trips was

$$\text{HB trips} = 2\ (\text{number of chains}) = 2\ (2.87) = 5.74$$

Therefore the number of non-home-based trips was given by Equation 12 as

$$\text{NHB trips} = (\text{total number of trips}) - (\text{HB trips}) = 7.27 - 5.74 = 1.53$$

Thus 21 percent of all trips were non-home-based and all others were home-based. This agrees with the figures in Sosslau et al. (*1*, pp. 13–14) and Allaman et al. (*4*, p. 18), which indicate that approximately 20 percent of all trips are non-home-based.

COMPARISON

In this section a comparison between the results presented in this paper and those from the previous study (*5*) is presented. The comparison is divided into three parts: a description of the differences between the two data sets, a summary of differences in the estimation results, and a discussion of the differences in model structure between the two studies.

The data set used in the previous study consisted of 1,739 households from the Dutch National Mobility Data Set, referred to as the Dutch data set. Details of this data set can be found in Golob et al. (*18*). The data set used in this study (the Detroit data set) contained 2,285 households.

The trip rates observed in the Dutch data set represent weekly household trip generation by purpose, whereas daily household trip generation was studied in this paper. In the Detroit data set, the average number of cars owned by a household was 1.59, whereas in the Dutch data set it was considerably lower (0.87 cars per household). The average household size, number of children, and number of licensed drivers (Detroit data set versus Dutch data set) were 2.92 versus 2.82, 0.89 versus 1.05, and 1.73 versus 1.36, respectively. The average total number of trips made by a household was 10.22 trips per day in the Dutch data set and 7.27 trips per day in the Detroit data set.

The composition of the household was the most important predictor for trip generation in both studies. As expected, this was particularly pronounced for school trips. In the Dutch study the presence of children in the household in the 12–17 age group contributed approximately one school trip per day. The same was found in this study.

The role of income in the trip generation models was substantially different for the two studies. In the Dutch study, income appeared to be significant for school trips and shopping trips but not for work trips. In this study, income was significant for work trip generation but not for the other trip purposes. This was partially due to the lack of employment and education information in the Detroit data set; presumably income enters the Detroit models as a surrogate for the employment and educational level of the household members.

Car ownership was an important predictor in the serve-passenger trip model on the Dutch data set (a set of dummy variables representing car ownership indicated high t-statistics). On the other hand, in the serve-passenger model for the Detroit data set, car ownership levels did not appear as explanatory variables (a series of specifications for this model did not yield significant car ownership coefficients at the 5 percent level). Given the higher car ownership levels in the Detroit data set, the serve-passenger trip generation may have been more directly influenced by the number of licensed drivers in the household, which was a significant variable in the model. Even though the importance of land use for trip generation was recognized in both studies, its effect was not explicitly incorporated in the models because of the unavailability of adequate land use variables.

Overall, the Detroit data exhibited more multistop trip chains than the Dutch data, in particular those involving work trips and shopping trips. On the other hand, social and recreational trips were more likely to be made in single-stop trip chains (home-stop-home) in the Detroit data. School trips were less likely to be linked with other trips in the Detroit model, whereas they were more likely to be linked according to the Dutch model. Personal business trips were not included in the Dutch study due to the small number of personal business trips reported in the data file, whereas they indicated a high propensity to be linked in this study.

In the Dutch data set, 15 percent of the trips were non-home-based. The corresponding figure in the Detroit data set was 21 percent. Considering the high levels of car ownership and dispersed pattern of land use development in the Detroit area and the tightly developed and more transit-oriented urban areas in the Netherlands (one of the most densely populated countries in Europe), this result is not surprising. However, these may have been but some of the factors contributing to the difference in trip chaining between the two areas. Possible effects of other factors still need to be investigated.

The structure of the model system in this paper is different from the one developed for the Dutch data set (see Figure 2). Most important, the Detroit system represented no negative correlation between discretionary and mandatory trips. This contrasts sharply with the Dutch system, in which the discretionary trips were negatively correlated with the mandatory trips, indicating the possible binding effects of time-space constraints.

The average household in the Dutch data set, compared with its counterpart in the Detroit data set, has fewer adults and more children, owns fewer automobiles, and has fewer drivers. Combined with other environmental factors—for example, the restrictive store hours (8 a.m.–5 p.m.) in the Netherlands—these characteristics represent a higher degree of constraint within which a Dutch household arranges its trips. The apparent discrepancy between the results from the two studies suggests the importance of environmental constraints on household travel. This also suggests that there is no universally applicable trip generation model system; a model system must be developed to capture the salient contributing factors in the study area by appropriately selecting its structure, explanatory variables, and model coefficients. The study results contradict the notion of transferability in trip generation models across study areas.

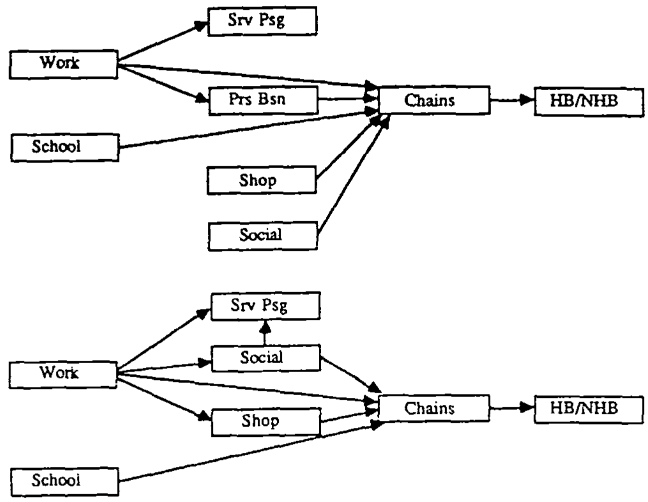

FIGURE 2 **Detroit (*top*) and Dutch (*bottom*) model systems.**

CONCLUSIONS

A model system was developed to depict trip generation in a more realistic manner through a recursive model structure representing trip generation by purpose. Concepts from the activity-based approach, trip chaining analysis, and conventional home-based and non-home-based trip generation were integrated in the proposed model system. One advantage of this method is that it reflects a possible multistage decision-making process that may be followed by households when making trips. Another important property of the model system is that it explicitly considers the interface among trips made for different purposes, thus integrating home-based and non-home-based trip generation in a coherent manner.

An important exercise of this study concerns the interpretation of the estimates of the coefficients in the trip chain model. The likelihood that a trip for a given purpose is combined with other trips into a trip chain was assessed from these estimates. Work trips, shopping trips, and personal business trips were linked into multistop chains more often than social trips and school trips.

A comparison of the results of this study (which was based on a Detroit data set) with those of a previous study [which was based on a Dutch data set (5)] offered useful insights into the differences in travel behavior under different environments. The salient element was the difference in the model structure. This was presumably due to differences in land use development, transit service levels, store opening hours and other institutional elements, and culture. The comparison suggests the need for further comparative analyses in trip generation, especially with regard to the transferability of model systems.

The model system needs further development to be a component of a comprehensive procedure of travel demand forecasting. For example, the model system developed in this paper cannot be used to predict the sequence in which trips for different purposes are linked. Consequently, it is unable to estimate home-based and non-home-based trip generation by purpose. If the proposed model system is to be used as part of the UMTA Transportation Planning System procedure, a model for trip sequencing must be introduced. This is the next step of this continuing effort.

ACKNOWLEDGMENTS

This research was supported by the National Science Foundation under a grant to the University of California at Davis and by the U.S. Department of Transportation Region 9 Transportation Center at the University of California at Berkeley. The comments and suggestions on an earlier version of this paper provided by the anonymous reviewers is gratefully acknowleged.

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