6. R.A. Feinberg and T.L. Snuggs. The Mobility Enterprise: Focus Group Interviews. Automotive Transportation Center, Purdue Univ., West Lafayette, Ind., July 1982.
7. R.A. Feinberg and T.L. Snuggs. The Mobility Enterprise as Innovation. Automotive Transportation Center, Purdue Univ., West Lafayette, Ind., May 1982.
8. R.A. Feinberg and T.L. Snuggs. Psychological Pricing and the Mobility Enterprise. Automotive Transportation Center, Purdue Univ., West Lafayette, Ind., June 1982.
9. W.G. Blom et al. High Speed Digital Data Acquisition System for Electric Vehicles. Proc., Electric Vehicle Council Symposium VI, EVC Paper 8120, Oct. 1981.
10. J.D. Fricker and J.K. Cochran. A Queuing Demand Model to Optimize Economic Policymaking for a Shared Vehicle Enterprise. Presented at the Operation Research Society of America (ORSA) and The Institute of Management Science (TIMS) Conference, San Diego, Oct. 25, 1982.

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Person-Category Trip-Generation Model

JANUSZ SUPERNAK, ANTTI TALVITIE, AND ANTHONY DeJOHN

A person-category model of trip generation is presented as an alternative to household-based trip-generation models. In this model a homogeneous group of persons is used as an analysis unit. The final description of the person categories is not arbitrary but results from the multistage, multivariate analysis of many potentially significant variables. The variables age, employment status, and automobile availability were found to be the most significant descriptors of a person's mobility. The final version of the model is based on eight person categories. Both theoretical discussion and empirical findings favor the proposed version of the person-category model over household-based models because it is more practical at the forecast stage, requires significantly less data, has better behavioral background, and is more compatible with the entire system of individually oriented travel-demand models.

The development and evaluation of a person-category trip-generation model as an alternative to household-based models are discussed in this paper. The individual-level approach was chosen for the following reasons. First, a person-level trip-generation model is compatible with other components of the four-step travel-demand model system that is based on tripmakers rather than on households. Second, it is extremely difficult to devise a household-based cross-classification scheme that uses all important variables and has a manageable number of classes [e.g., a British household cross-classification model (1) has 108 categories]. Predicting representations in so many classes is difficult.

Third, the sample size for the person-category model can be much smaller (10 to 40 times) than for the household-category model. Fourth, demographic changes can be more easily accounted for in the person- rather than household-category model, and some demographic variables (such as age) are virtually nondefinable for households. Finally, person categories are easier to forecast to the future than the household categories, which require forecasts about household formation and family size. With the person categories these tasks are altogether avoided. More importantly, because the bulk of the trips will be made by people older than 18 years of age, the task of predicting the tripmaking population 15 to 20 years ahead is much easier.

There are of course some limitations that a person-category model may have. Foremost among these is the difficulty of introducing household-interaction effects and household money costs and money budgets into the model. On the other hand, it is not clear how vital these considerations are and how they can effectively be introduced even in a household-category model. The methodology of the development and testing of the person-category model was based on previous work from Europe (2-6), where the person level of data aggregation was found to be successful for travel-demand analysis.

DATA AND DEFINITIONS

Data

The data used in preparing this paper were from the Baltimore home interview survey conducted in 1977 by the FHWA and from Minneapolis-St. Paul home interview data collected in 1970. Before the analyses, data were superfically cleaned. Workday records were separated from weekend-day records, and some persons were excluded from the original sample. For example, if in the original file a significant inconsistency was found (e.g., number of cars in the family = 7 and number of drivers = 0), the person was excluded. Outliers were also excluded. If the number of trips done by a person was greater than 10 and if total time spent on traveling during the day exceeded 150 min, then this person was suspected to be a professional driver (or similar category) and was excluded from the sample.

Definitions

The following definitions are used in the analyses:

N_i = trip rate, that is, the daily number of one-way trips made by (average) person in category i; and N_{qi} = trip rate to purpose q in category i;
T_i = daily travel time; that is, the time (in minutes) spent by (average) person in category i on traveling during the day;
Y_j = total number of trips made anywhere by the inhabitants of zone j (all categories together);
L_j = number of zone j inhabitants; and
α_{ij} = percentage of inhabitants of zone j belonging to category i.

Thus the following basic relationship is given:

$$Y_j = L_j \sum_i \alpha_{ij} N_i \tag{1}$$

The method of calculating zonal productions (P_j) and attractions (A_j) is not presented in this paper. This method is briefly presented in Supernak (5).

In analyzing and calculating trip rates, trips are divided into

1. Home-based (HB) trips if origin (HBO) or destination (HBD) of the trip is the place of residence of the traveler, and
2. Non-home-based (NHB) trips if neither origin nor destination of the trip is at home.

Trips are further divided by trip purpose (q) as follows: work (W), education (E), shopping (S), personal business (Pb), and social-recreational and other purposes (Sr). This trip-purpose classification applies to both HB and NHB trips. Work and education trips are called obligatory trips, and all other trips are called discretionary trips. The traditional description of the trip links (instead of sojourns of trips) was chosen because it clearly relates the number of outside-the-home activities to the number of trips made (6,7).

An example of trip rates for category i is given in Table 1. Fifteen-element vectors of partial trip rates N_{qi} (i.e., separated by purpose, direction, and base) may be derived from the data, as shown in Table 1; they served as the trip characteristic of category i.

Table 1. Example of trip rate characteristic N for category i.

	Obligatory		Discretionary			
Trip	W	E	S	Pb	Sr	Total[a]
HBO	0.86	0.02	0.10	0.21	0.05	1.33
HBD	0.86	0.05	0.21	0.19	0.02	1.33
NHB	0.02	0.05	0.14	0.14	0.07	0.43
Total[a]	$N_i^{obl} = 1.86$		$N_i^{disc} = 1.24$			$N_i = 3.10$

[a]Note that some columns will not total because of rounding.

ANALYSIS PROCEDURE

The model development was done in four stages:

Stage 1--(a) arbitrary choice of many variables, which are expected to be important for explaining differences in a person's mobility, and definition of plausible person categories by using these variables; and (b) preliminary analysis of trip rates (N_i) and trip times (T_i) to find which variables have the least explanatory power and can be excluded from the model;

Stage 2--(a) detailed analysis of trip characteristics to find variables that define similar categories for stage 3; variables that do not give substantial explanation of the data variance or variables that duplicate an explanation of other better variables are excluded; (b) proposal for the final trip-generation categories, the number of which should not exceed a certain practical maximum (for example, 10); and (c) analysis of dependency of trip rates between trip purposes [not reported in this paper, see Supernak et al. (8)];

Stage 3--(a) final trip-generation characteristics of each category, as determined in stage 2, are analyzed in detail; and (b) transferability of the results within different sections of Baltimore and to other cities is examined; and

Stage 4--comparison with household-based trip-generation model, as presented in detail in DeJohn (9).

The statistical methods used in the analyses are simple and straightforward. At all times these statistical methods are supplemented by visual analysis of data that try to find patterns in the data that a blind application of statistical methods may not find.

In stage 1 of the model development only a pairwise comparison of total trips rates is performed. The Z-statistic for the trip rates of two categories i and j, which are differentiated by the analyzed variable only, is computed and compared with the critical Z-value at the 0.01 level of significance.

In the remaining stages three additional measures supported by histograms and analyses of variance are used. These three measures are the correlation coefficient, slope (m), and intercept (b) of the regression $N_{qi} = b_{ij} + m_{ij}N_{qj}$.

The categories i and j may be treated as similar if (a) the correlation coefficient between vectors of the partial trip rates (i.e., trip rates by purpose and base) N_{qi} and N_{qj}, and (b) the parameters of the regression coefficients (m_{ij} - slope, b_{ij} - intercept), satisfy the following conditions:

$$r_{ij} > 0.900 \quad (2)$$

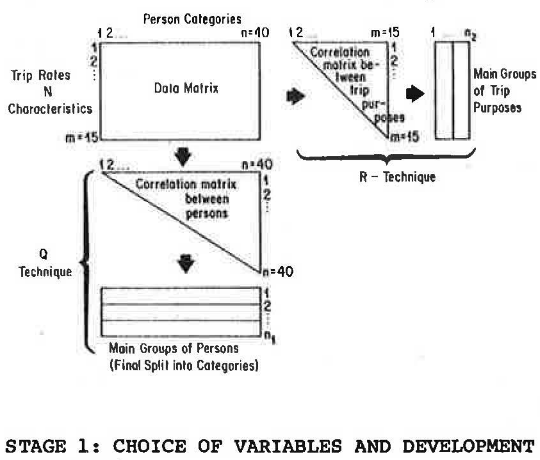
$$0.75 < m_{ij} < 1.25 \quad (3)$$

$$|b_{ij}| < 0.10 \quad (4)$$

These conditions are arbitrarily chosen and are quite demanding.

These three measures can be used to analyze the appropriate categories for both persons and trip purposes, as shown in Figure 1. The Q-type regression and correlation analysis is used for analyzing the best grouping of persons, and the R-type analysis is used for grouping trip purposes. These analyses are useful for both travel-demand analysis (3,4) as well as for nontransportation applications (10).

Figure 1. Q-type and R-type analysis of trip rates N_{qi}.



STAGE 1: CHOICE OF VARIABLES AND DEVELOPMENT OF CATEGORIES

For stage 1, the following variables (and strata) were used to form the categories.

1. Sex: The obvious choice of strata here is male and female.
2. Age: Age was used to describe the main activity at a given age (primary school pupils, high

school pupils, college students, employees, retired). Accordingly, the age groups used were 0 to 12, 12 to 18, 18 to 65, and older than 65. Age 40 is also used to divide the employable work force into two categories.

3. Car availability: In all known trip-generation models the variable car ownership was used and treated as a basic variable. Here a variable defined as car availability is used. The reason for this change comes directly from the general concept of the model. When using a traveler or a person as the analysis unit, car ownership of the family is not directly related to the car availability of different family members. Thus the following distinction was made (where N_c = number of cars in the household and N_d = number of drivers in the household). For a given person, car availability is (a) never available if $N_c = 0$ or $N_d = 0$ (person has no driving license) or (b) sometimes available if $N_c > 0$ and $(N_c/N_d) < 1$ $(N_d > 0)$ or (c) always available if $(N_c/N_d) > 1$.

4. Employment status: Status is divided by employed and not employed.

5. Income: Income is defined at the individual level rather than at the family level. Household income was converted to per capita income simply by dividing it with family size.

6. Race: The race variable (white versus nonwhite) was analyzed because of the significant percentage of nonwhite respondents in the Baltimore data set.

7. Employment types: Three strata are used--white collar, blue collar, and other.

8. Family type: Five family types were analyzed to understand how the family duties affected a person's tripmaking behavior. The strata of this variable were as follows: single person, childless couple, family with children younger than 5 years of age, family with children 5 to 12 years of age, and family with children older than 12 years of age.

These variables and strata resulted in the 100 categories shown in Figure 2. (Note that Figure 2 is read in the following way: each dot indicates which variable applies. For example, persons in category 24 are white, single, employed blue-collar males who have a car always or sometimes available and whose per capita income is between $1,500 and $4,000 per year; there are 11 such persons in the sample.) Note that in defining these categories many potentially important variables were included initially, and yet there was a desire to keep the number of categories reasonable (i.e., not to exceed 100). The eight variables could have produced 5,400 categories, whereas the sample size was only about 2,000. The categories were also defined in such a way so as to avoid impossible or improbable combinations of variables and to avoid extremely unequal representation in each category. Therefore, no computerized procedure to generate categories automatically, which would be otherwise useful, was applied. The initial arbitrary split into categories is presented in Figure 2.

The aim of the analysis at this stage was to discover which variables have the least effect on trip-generation rates and can be removed from consideration. A convenient method used was a series of pairwise comparisons performed for categories i and j, which differ with respect to one variable only. An example of such an analysis is given in Table 2.

The results of the stage 1 analyses are summarized in Table 3. Some variables always give a significant and regular explanation of patterns in tripmaking. These variables are car availability, employment status, age, and sex. Income might be significant if only two levels (higher, lower) were introduced and, therefore, deserved further investigation.

Other variables such as family status, race, and employment type gave unsatisfactory explanations and were excluded from the second stage of the model. The proposal for further analysis of the category definition is shown in Figure 3 and is analyzed in the next section.

It is worth dwelling on the significant result that household type does not appear to be an important descriptor of a person's tripmaking behavior. One of the major arguments made in favor of the household level of data aggregation is that family structure (e.g., number of children of different ages) affects travel behavior of adults in the household. It was claimed, therefore, that the family's needs (and consequently trips) should be analyzed together with special reference to interactions within the family.

The result here suggests that adults will fulfill their transportation needs (measured by trip rates) independently of their family situation; the sources of variation in data are outside the family-structure variable. This result supports the person level of data aggregation applied here. It is also worth noting that, with the exception of single-member households, the sample size is rather large (>250), and the result obtained should not be a statistical artifact.

STAGE 2: ANALYSIS OF TRIP RATES AND DEVELOPMENT OF FINAL PERSON CATEGORIES

Pairwise Analysis of Remaining Variables

The total trip rates (trips per person) and travel times (total daily travel time per person) by age groups, sex, automobile availability, employment status, and income, as well as the results of pairwise comparisons of trip rates for each strata, are given in Table 4. The accompanying figures (Figures 4-7) provide a graphic analysis of two or more factors that the pairwise comparison is unable to do. These graphs are useful in understanding basic relationships between variables.

The results given in Table 4 and shown in the accompanying figures suggest that the most important variables are age, employment status, and car availability. Sex and income appear to be weak variables. Their independent effect when analyzed together with car availability or employment status tend to disappear altogether (for example, see Figure 4, which is an analysis of employment and sex).

Traveling activity, measured by trip rates N and by daily travel times T, declines with age (Figure 5). Most dramatically this is true for the obligatory trip, which declines substantially after retirement.

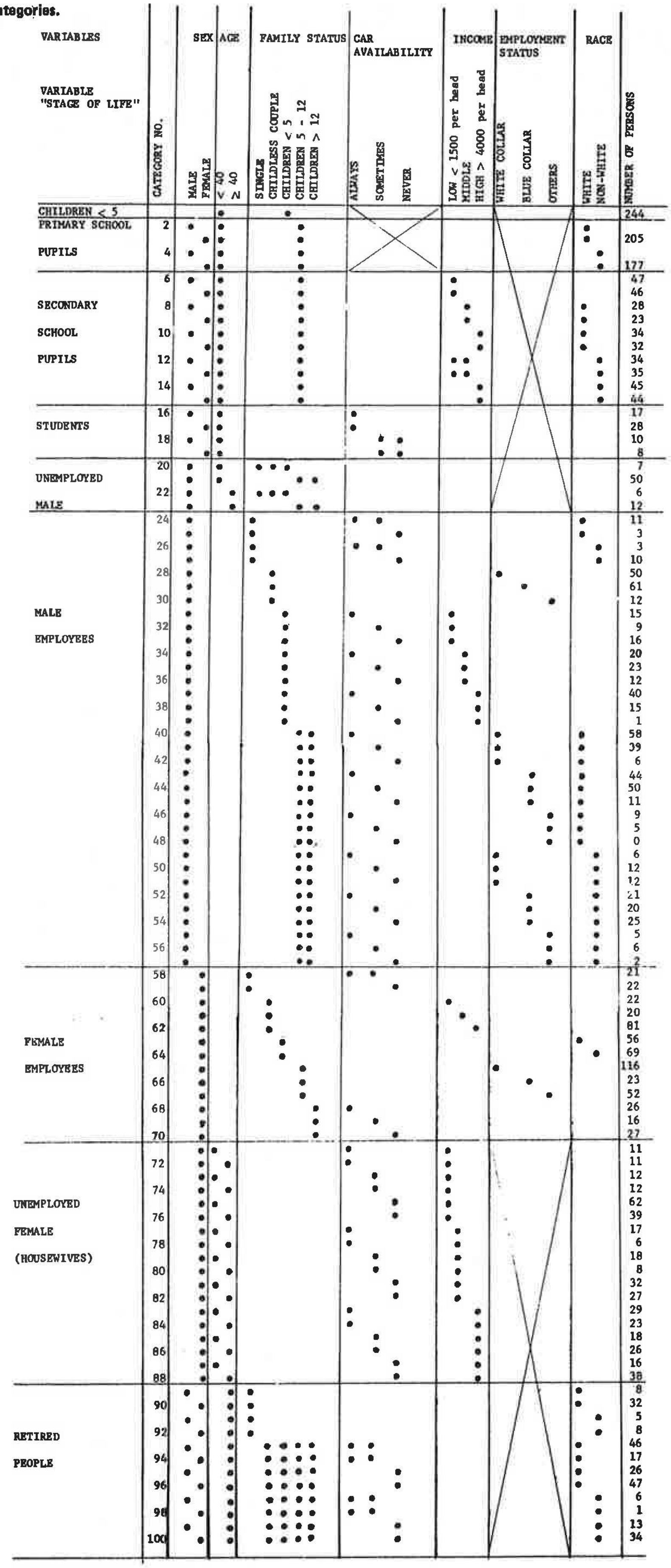
Employment (i.e., the existence of obligatory activity) is a basic factor for explaining the differences in trip rates and daily travel, as shown in Figure 6. Car availability is also of great significance; this is especially true for distinguishing the tripmaking patterns of those who do not have cars available from those who do have cars available (see Figure 7).

The obvious reasonableness of these conclusions supports the modeling approach by which they were derived. A more thorough analysis of data will be described next to define the final categories.

Q-Type Correlation Analysis of 40 Person Categories

Based on previous results, four versions of the final categories shown in Figure 8 might be considered. In these groupings age is divided into

Figure 2. Primary split into 100 categories.



three strata: younger than 18, 18 to 65, and older than 65. The pairwise analysis suggested that the age groups younger than 40, 40 to 65, and older than 65 may be most appropriate. However, plots in Figures 4-7, which consider more than one variable, as well as practical considerations, favor the first-mentioned age strata. The first stratum consists of (mostly) unemployable students, the second stratum includes the labor pool, and the third stratum includes retired people.

Four versions of category descriptions were analyzed (Figure 8). Version D is preferred because it is a parsimonious grouping of people into only eight categories; however, it must be based on a more

Table 2. Analysis of variable age: trip rates for younger versus older housewives.

Category No.		Trip Rates N_i	
Age < 40	Age ≥ 40	Age < 40 (n = 215)	Age ≥ 40 (n = 190)
71	72	3.36	2.81
73	74	3.00	2.33
75	76	1.42	0.85
77	78	2.18	1.50
79	80	1.89	1.13
81	82	1.12	0.70
83	84	3.86	3.65
85	86	2.72	2.27
87	88	1.50	1.52
		2.11[a,b]	1.73[a,c]

[a]Mean of total trip rate.
[b]$Z_{1,2}$ = 4.00.
[c]$Z_{0.01}$ = 2.30.

Figure 3. Stage 2 description of person categories.

CAT	AGE	SEX	AUTO	EMP	INC
0	1				
1	2	1			
2	2	2			
3	3	1	1	1	1
4	3	1	2	1	1
5	3	1	3	1	1
6	3	1	1	1	2
7	3	1	2	1	2
8	3	1	3	1	2
9	3	1		2	
10	3	2	1	1	1
11	3	2	2	1	1
12	3	2	3	1	1
13	3	2	1	1	2
14	3	2	2	1	2
15	3	2	3	1	2
16	3	2	1	2	
17	3	2	2	2	
18	3	2	3	2	
19	4	1	1	1	1
20	4	1	2	1	1
21	4	1	3	1	1
22	4	1	1	1	2
23	4	1	2	1	2
24	4	1	3	1	2
25	4	1		2	
26	4	2	1	1	1
27	4	2	2	1	1
28	4	2	3	1	1
29	4	2	1	1	2
30	4	2	2	1	2
31	4	2	3	1	2
32	4	2	1	2	
33	4	2	2	2	
34	4	2	3	2	
35	5	1	1		
36	5	1	2		
37	5	1	3		
38	5	2	1		
39	5	2	2		
40	5	2	3		

Variable Levels:

- AGE: 1. <12; 2. 12-18; 3. 19-40; 4. 41-65; 5. >65
- SEX: 1. Male; 2. Female
- AUTO AVAILABILITY: 1. Never; 2. Sometimes; 3. Always
- EMPLOYMENT: 1. Employed; 2. Non-employed
- INCOME: 1. < $3000/cap; 2. ≥ $3000/cap

Table 3. Pairwise comparison of trip rates by variable categories (stage 1).

Variable	Category	Total Trip Rate[a] 1 Mean	1 No.	2 Mean	2 No.	3 Mean	3 No.	4 Mean	4 No.	Z-Values[b] ($Z_{0.01}$ = 2.57, $Z_{0.05}$ = 1.96) 1,2	1,3	2,3	Comments
Sex	Male, female	2.65	811	2.20	1,093					7.89	–	–	Significant difference in trip occurred only for persons >65; this group alone may not warrant stratification by sex
Age	12-18, 18-65, >65	2.92	482	2.56	1,661	1.23	243			4.82	–	26.3	Younger persons travel more
Age, housewives only	<40, ≥40	2.11	215	1.73	190					4.00	–	–	Younger persons travel more
Car availability	Never, sometimes, always	1.38	309	2.78	289	3.23	341			15.4	–	3.8	Differences between car never, sometimes, and always available are significant; greater car availability means more trips
Employment status	Employed, not employed	2.85	1,183	1.85	478					17.0	–	–	Whether a person is employed or not is an extremely significant variable
Income	Low, middle, high	1.89	187	1.85	163	2.83	206			0.40	–	8.00	Trip rates between high and other income groups are different
Race	White, nonwhite	2.25	398	1.98	176					2.88	–	–	This is an extremely erratic variable; visual examination of data did not suggest stratification by race; difference caused by four categories (46, 59, 94, 98)
Employment type	White collar, blue collar, other	3.05	133	2.67	171	2.92	27			2.28	0.42	0.83	Not a significant variable
Household type	Single, couple, couple with children <5, couple with children >5	2.90	70	2.78	246	2.82	276	2.80	591	0.62	0.21	0.32	Family type is not significant ($Z_{3,4}$ = 0.10)

[a]The columns in this section are read as follows. The strata for each variable are defined under the Variable and Category columns; e.g., car availability—never, sometimes, always, and the trip rates in columns 1, 2, and 3 pertain to these strata in the codes shown (i.e., 1 for never, 2 for sometimes, and 3 for always).
[b]Z-values are calculated by comparing the mean trip rates for the columns shown.

Table 4. Pairwise comparison of trip attributes by category (stage 2).

			Characteristics of Attributes												Z-Value of Pairwise Comparison of Means of Attributes				
			1			2			3			4							
Variable	Category	Attribute	Mean	SD	No.	Mean	SD	No.	Mean	SD	No.	Mean	SD	No.	$Z_{1,2}$	$Z_{1,3}$	$Z_{1,4}$	$Z_{2,3}$	Comments
Age	<18, 18-40, 41-65, >65	N	2.88	2.05	347	2.77	2.01	698	2.40	1.76	586	1.25	1.67	195	0.82	3.65	3.50	3.50	$Z_{2,4}$ = 10.72, $Z_{3,4}$ = 8.23
		T	51.8	37.2	347	52.8	38.0	698	47.9	35.2	586	22.0	31.2	195	0.40	1.17	9.94	2.40	
Sex	Male, female	N	2.69	2.05	816	2.37	1.98	1,010							3.37	–	–	–	Sex alone is a significant variable, but when plotted together with employment status its significance disappears
		T	53.8	38.9	816	42.7	36.5	1,010							6.57	–	–	–	
Automobile availability	Never, sometimes always	N	1.55	1.58	501	2.86	2.05	349	3.23	1.95	483				10.05	14.80	–	4.23	Important variable
		T	32.6	36.1	501	54.8	35.8	349	60.6	38.2	483				8.86	11.80	–	2.23	
Employment status	Employed, not employed	N	3.05	0.19	1,086	1.71	1.43	740							21.18	–	–	–	Important variable
		T	61.4	39.4	1,086	27.8	34.7	740							19.22	–	–	–	
Income	Low, high	N	2.78	2.05	217	3.27	2.23	522							2.88				Income is not a strong variable; for T it is not a significant stratifier even when considered alone
		T	62.8	39.1	217	67.2	42.3	522							1.42				

Note: This table is read in the same manner as Table 3. N = trip rate and T = total travel time.

Figure 4. Values of N and T as dependent on employment, sex, and age of persons.

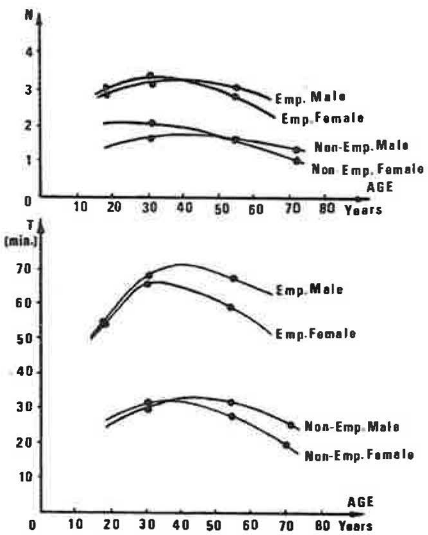


Figure 5. Values of N and T for obligatory and discretionary trip purposes as dependent on age of persons.

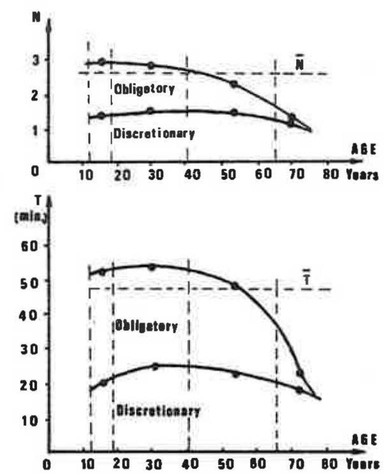


Figure 6. Values of N and T as dependent on age of persons and employment status.

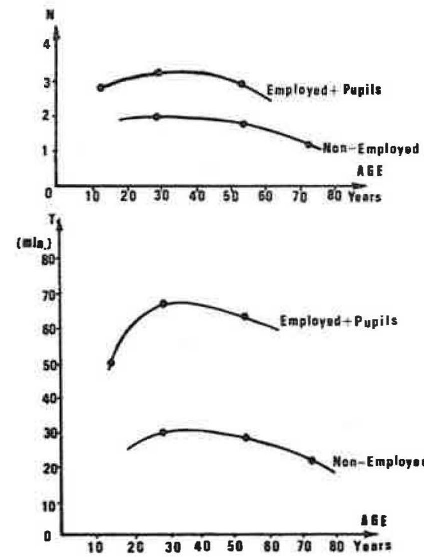


Figure 7. Values of N and T as dependent on car availability and age of persons.

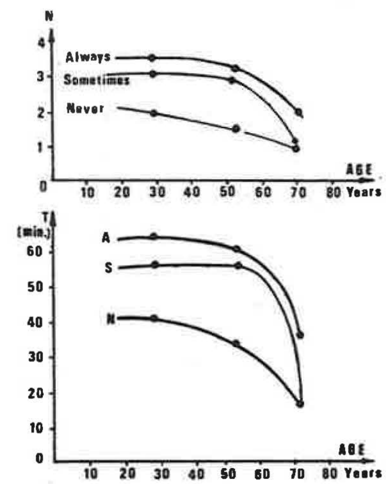
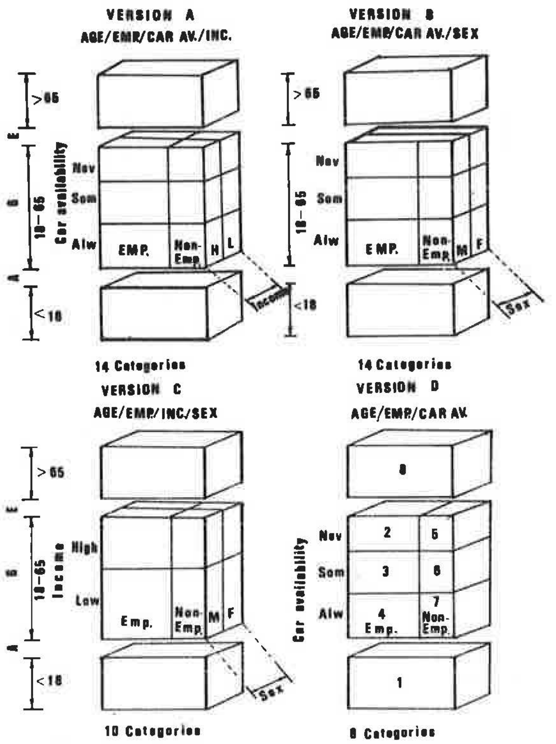


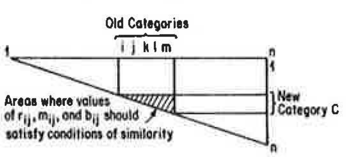
Figure 8. Four versions of person-category definition.



detailed examination of the data using the 15-element trip rate vector (N_{qi}) shown in Table 1 and calculated for each category.

For all four versions of the final category definition, respective triangle matrices of r_{ij}, m_{ij}, and b_{ij} were found (the Q-type analysis). From the analysis point of view, the interesting parts of these matrices are those near the hypothenuse, where the values of r_{ij}, m_{ij}, and b_{ij} are expected to satisfy conditions of similarity given earlier (Equations 2-4) for those old categories i, j,..., m, which will be combined in one new category C (Figure 9).

Figure 9. General idea of creating and evaluating new final person categories.



The shadowed triangles in Figure 9 that were near hypothenuses of the matrices r_{ij}, m_{ij}, and b_{ij} were examined carefully. As one of the possible measures of appropriateness for each four versions of the final category description, the average regression for pairs of categories in the shadowed areas was calculated.

The results of the regressions [see Supernak et al. (8) for details] indicated that a 14-category version is only slightly better than the 8-category version. This conclusion is also supported by visual inspection of the triangular matrices for r_{ij}, b_{ij}, and m_{ij} (8).

Further detailed examination of the matrices for r_{ij}, b_{ij}, and m_{ij} led to three specific comments. First, there are three main groups of travelers that have clearly different trip-generation characteristics: people under the age of 18 (mostly students), employed adults (age 18 to 65), and not employed adults and retired people. Second, the conditions taken as a measure of similarity ($r_{ij} > 0.900$, $0.75 < m_{ij} < 1.25$, $b_{ij} < |0.10|$) are satisfied for most pairs of old categories, which are consolidated into the final new categories. These criteria are better met by the student and employed adult categories than by the not employed and retired categories. It means that the existence of an obligatory activity (work, school) makes travelers' behavior more regular. Third, unsatisfactory values of r_{ij}, m_{ij}, and b_{ij} observed in some cases were regularly accompanied by small size in the categories.

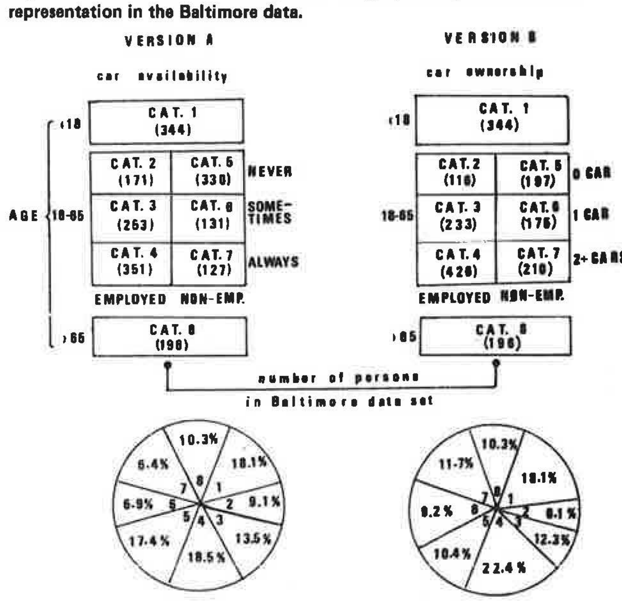
The correlation analyses and the pairwise comparisons strongly suggest that the final categories should be based on age (younger than 18, 18 to 65, older than 65) and employment status (employed, not employed). Of the remaining variables, either car availability or sex and income could be used. For practical reasons, to keep the numbers of categories low and variables compatible with other models, car availability was chosen to complete the list of variables for defining trip-generation categories. A two-dimensional analysis of variance was done to provide quantitative support for this choice; the results indicated that sex and income do not have much explanatory power when analyzed together with car availability.

STAGE 3: FURTHER ANALYSIS OF FINAL TRIP-GENERATION CATEGORIES

The final eight person categories were based on three variables: age, employment status, and car availability. These eight categories are analyzed in more detail.

Car availability data may be replaced in the model by car ownership, the latter in some cases being more readily available. The results of a version A (using car availability) and those of a version B (using car ownership) are compared in Figure 10. For practical model applications, both versions require estimation of category representa-

Figure 10. Two versions of final person-category description and their representation in the Baltimore data.



tions at the zonal level. This can be achieved by applying the person-category car-availability and ownership model, which is presented in detail in Supernak et al. (11). This model uses land use and level-of-service variables and thus takes into consideration the influence of these variables on both the category representations and final trip rates in the given area.

Figure 10 compares these two versions of the final trip-generation categories in the available sample. The weekday trip-generation rates for the two versions are given in Table 5 for all trips and in Table 6 for vehicular trips only. The data indicate that there is little difference whether car availability or car ownership is used. The biggest difference is in discretionary trips by car-owning persons. Generally, version A of the model formulation is recommended because it clearly refers to the person (a real or potential traveler) and his access to transportation models and his individual travel choices. The person-category car-availability model (11) is a direct input to the person-category trip-generation model. Both models require only routinely available data and are easy in practical application.

A comparison of the data in Tables 5 and 6 indicates the importance of walk and other nonvehicular trips (e.g., bike, horse, boat). For example, for persons not owning cars these trips account for 40 to 60 percent of all trips. For young people this percentage is greater. This is important because there clearly exist substitution possibilities between walk and bike and vehicular modes, and these should be accounted for in the models. It also appears that there is a distinct difference between employed and not employed persons' trip rates; the same is true for the car-ownership and car-availability groups.

For example, non-home-based vehicle trips (during weekdays) are more numerous for employed persons and increase with higher automobile availability level, which is an expected finding.

Also, modal choice is strongly related to the person category for both obligatory and discretionary trips. Employed persons are more likely to drive than not employed persons; public transit is rarely used by those with car always available, and the same applies to discretionary trips by persons with any access to a car; also the percentage of walk trips increases with decreasing car availability and is larger for discretionary trips. Again, the walk trips are of no small significance; they are more common than the transit trips (7, Figure 3).

Table 5. Trip-generation rates (trips per person) for eight person categories, weekdays only (stage 2).

Category No.	Home Based Obligatory A	Home Based Obligatory B	Home Based Discretionary A	Home Based Discretionary B	Non-Home Based A	Non-Home Based B	Total A	Total B
1	1.47	1.47	1.13	1.13	0.38	0.38	2.98	2.98
2	1.40	1.27	0.59	0.70	0.51	0.57	2.50	2.54
3	1.77	1.69	0.85	0.85	0.55	0.59	3.17	3.23
4	1.67	1.72	1.05	0.90	0.76	0.68	3.48	3.30
5	0.13	0.15	0.89	0.93	0.31	0.35	1.33	1.43
6	0.34	0.23	1.74	1.39	0.47	0.43	2.55	2.05
7	0.30	0.27	2.10	1.66	0.59	0.43	2.99	2.36
8	0.12	0.12	0.93	0.93	0.43	0.43	1.48	1.48
Weighted avg of population	1.01		1.07		0.50		2.59	

Note: Categories in versions A and B are defined in Figure 10.

Table 6. Trip-generation rates (vehicle trips per person) for eight person categories, weekdays only.

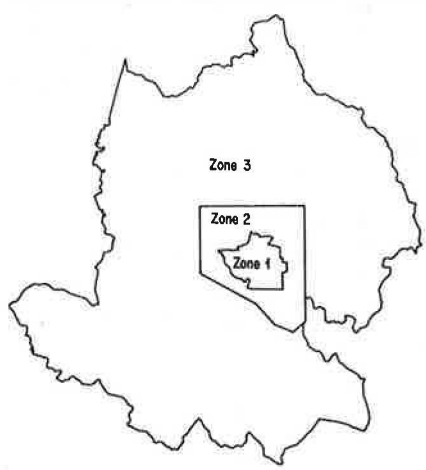
Category No.	Home Based Obligatory A	Home Based Obligatory B	Home Based Discretionary A	Home Based Discretionary B	Non-Home Based A	Non-Home Based B	Total A	Total B
1	0.63	0.63	0.48	0.48	0.15	0.15	1.26	1.26
2	1.15	0.98	0.28	0.28	0.28	0.27	1.71	1.53
3	1.64	1.57	0.76	0.83	0.49	0.52	2.89	2.91
4	1.61	1.61	0.96	0.82	0.71	0.63	3.28	3.09
5	0.06	0.06	0.40	0.31	0.14	0.11	0.60	0.48
6	0.28	0.16	1.39	1.04	0.38	0.32	2.05	1.52
7	0.24	0.21	2.03	1.50	0.57	0.39	2.84	2.10
8	0.12	0.12	0.60	0.60	0.28	0.28	1.00	1.00
Weighted avg of population	0.80		0.75		0.36		1.91	

Note: Categories in versions A and B are defined in Figure 10.

TRANSFERABILITY OF MODEL WITHIN THE BALTIMORE AREA

To examine the performance of the person-category trip-generation model, it was applied to three different areas of the Baltimore region. Area 1 is the central urban area (628 persons), area 2 is the remainder of the urban area (617 persons), and area 3 is the suburban area (622 persons) (see Figure 11).

Figure 11. Baltimore region divided into three areas.



A transferability error analysis of areawide trip rates, nonwork vehicle trip rates, and the automobile drive portion of modal split for subareas 1 and 3 is given in Table 7. The data indicate that the categorization of persons reduces the percentage error in the average trip rate, and thus in travel-demand prediction, often by more than 50 percent, which leaves the remaining error rather low. The remaining errors for total trip rates (N, N^{obl}, N^{disc}) are smaller for the recommended version A of the model formulation than for version B. The data also indicate that person categories provide a satisfactory explanation of automobile driver modal-split percentages (it can even be argued that these are better results than the results obtained with a sophisticated modal-split model).

Table 7. Comparison of transferability errors for subareas 1-3 in Baltimore with and without category division.

No.	Value	Category Split Version	Zone 1: Central Urban — Percentage Error without Category Split[a]	Zone 1: Central Urban — Percentage Error with Category Split[b]	Zone 3: Suburban — Percentage Error without Category Split[a]	Zone 3: Suburban — Percentage Error with Category Split[b]
1	N	A	+23.3	+10.5	-14.2	-6.6
		B		+12.8		-8.6
2	N^{obl}	A	+29.1	+9.3	-11.2	-3.2
		B		+8.1		-3.2
3	N^{disc}	A	+19.4	+11.9	-16.4	-1.7
		B		+19.4		-15.8
4	$N^{nonwalk}$	A	+57.0	+26.5	-26.4	-14.3
		B		+18.7		-15.4
5	Percentage of discretionary nonwalk trips	A	+51.9	+31.2	-18.2	-13.3
		B		+29.9		-16.0
6	Percentage of drive-alone trips	A	+86.8	+7.4	-37.6	-15.3
		B		+16.9		-11.4

[a]Calculated as $(\bar{N}_{ave} - \bar{N}_j)/\bar{N}_j$, where j = area.
[b]Calculated as $\left(\sum_i \alpha_{ij} N_{ij} - N_j\right)/N_j$, where α_{ij} = percentage of sample in category i who reside in area j.

The numbers in Table 7 also call for caution in treating walk trips. The data indicate that there is an overprediction of nonwalk trips in the urban area by about 30 percent, and an underprediction of nonwalk trips in the suburban area by about 15 percent, even when person categories are used; thus walking is an important mode.

Overall, this analysis demonstrates the usefulness of categorization of the population into eight segments. The conclusion from the data in Table 7, however, should not be that trip-generation forecasts based on person categories provide a substantial improvement over trip-generation forecasts based on average (one category) trip rates. This would be a trivial finding. Rather, the conclusion is that the remaining transferability errors are low, keeping in mind that sample size in Baltimore subareas is only about 600.

Another transferability test was performed between Baltimore and the Twin Cities of St. Paul-Minneapolis (12). Unfortunately, this comparison could be made for travelers only and their vehicular trips because the data records in the Twin Cities were not complete. The trip rates of eight categories appeared to be similar for those two cities, and the transferability errors were low. However, because the analysis unit traveler is not recommended for trip-generation analyses, this part of the research is not presented in this paper. More details about transferability of the person-category trip-generation model are given in Supernak (13).

COMPARISON WITH HOUSEHOLD CATEGORY MODEL AND CONCLUDING REMARKS

For comparison purposes, a household-category model was developed in the same way as the person-category model (9). Because there were only 609 households (but 1,825 individuals) in the Baltimore data (weekdays), the analyses lacked the richness of the person-category model.

Based on previous research (1,14,15), three variables were chosen for the analyses: household size (one, two, three, four, five or more), car ownership (zero, one, two or more), and number of employed household members (one, two, three or more). Unfortunately, other variables such as income and race could not be included because the chosen variables already yielded 51 categories, and the sample size was only 609.

Some results of the pairwise comparison of trip rates are given in Table 8. One unexpected result is noticed. The household-size variable is the only one that gives expected, consistent results. Household size appears to overshadow all other differences; this of course is a trivial finding (i.e., more people, therefore more trips). This result is substantial because it indicates the inefficiency and simplicity of the household-category model. The person-category model totally avoids these types of trivialities and the difficulty of predicting household size [for substantial errors in predicting household size, see Talvitie et al. (16)].

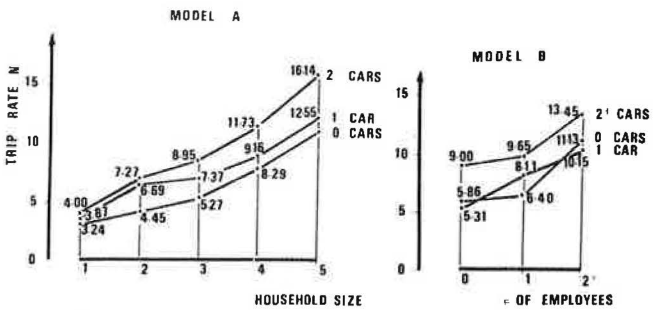
Table 8. Results of pairwise comparison of trip rates for different variable strata.

Variable Examined	Stratum i	Stratum j	Z_{ij}
Car ownership	0	1	2.24
	1	2+	4.24
Household workers	0	1	1.48
	1	2	1.76
	2	3+	4.17
Household size	1	2	4.80
	2	3	2.70
	3	4	3.39
	4	5+	3.89

Note: $Z_{0.01} = 2.57$.

The two models discussed next are two-dimensional combinations of the three variables. The first model, model A, has 15 categories of household size (one, two, three, four, five or more) and car ownership (zero, one, two or more). Model B has nine categories of workers (zero, one, two or more) and car ownership (zero, one, two or more). Trip rates for these models are shown in Figure 12. Model A shows consistency; that is, trip rates increase with car ownership and family size. Model B does not show consistency; that is, the trip rate for one-car families is less than the zero-car households when there are zero or two or more workers in the household. This outcome is difficult to explain and suggests that model A is the better model because introduction of one more variable (e.g., household size) would increase the number of categories to make the model impractical. It may be recalled that

Figure 12. Household model trip rates.



employment status was the key variable in the person-category model.

Examination of the performance of model A was difficult. Because of reasons of data incompatibility, a transferability check with Minneapolis-St. Paul data was impossible. The scarcity of data required that the Baltimore region be divided only into two areas, instead of the three used with the person-category model, to examine the transferability properties of the model. The remaining transferability error between the two zones was approximately 15 percent, or slightly more than for the person-category model (6 to 12 percent for the recommended version). Nevertheless, the findings are not comparable because the Baltimore subareas were defined differently.

Principally, then, the person-category model is favored for the following reasons. First, it classifies people in a manner that is logical and eliminates the necessity of predicting household formation and, especially, household size with their attendant difficulties. The research also indicated that household type was an unimportant variable in explaining person trip generation. Second, data are used much more efficiently in the person-category model than in household-category model, or, alternatively, less data are needed for developing the person-category model. Third, fewer categories may be used in the person-category model. Because household size is the key variable in household-category model, it precludes the introduction of real behavioral variables (such as age, employment status, and others) if the number of categories is to be kept within practical limits. This renders the household-category model trivial.

Finally, the person-category model has a better behavioral background because the analysis unit is identical with the traveling unit. This makes the person-category trip-generation model compatible with other models in the entire travel-demand model system. The person-category car-availability model, which is fully compatible with the person trip-generation model, makes references to the land use and level-of-service variables that where found to be significant in previous aggregate models, but were not present in most household-category trip-generation models. Therefore, the person-category trip-generation model reported in this paper is considered to be useful and practical and superior to a household-category model.

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REFERENCES

1. H.Y. Wooton and G.W. Pick. A Model for Trips Generated by Households. Journal of Transport Economics and Policy, No. 1, 1967.
2. U. Böhme. Grundlagen zur Berechnung des städtischen Personenverkehrs. Technische Universität Dresden, Dresden, German Democratic Republic, Ph.D dissertation, 1970.
3. E. Kutter. Demographische Determinanten städtischen Personenverkehrs. Technische Universität Braunschweig, Braunschweig, Federal Republic of Germany, 1972.
4. J. Supernak. Travel Demand Models for Polish Cities. Technical University of Warsaw, Warsaw, Poland, Ph.D dissertation, 1976 (in Polish).
5. J. Supernak. A Behavioral Approach to Trip Generation Modeling. Presented at the 7th Planning and Transport Research and Computation, Ltd. Summer Annual Meeting, Univ. of Warwick, Coventry, Warwickshire, England, 1979.
6. J. Supernak. Travel Demand Models. WKIL, Warsaw, Poland, 1980 (in Polish).
7. J. Supernak. Travel-Time Budget: A Critique. TRB, Transportation Research Record 879, 1982, pp. 15-28.
8. J. Supernak, A. Talvitie, and A. DeJohn. Analysis of the Person Category Trip Generation--Split into Forty Categories. State Univ. of New York, Buffalo, Working Paper 782-11, 1980.
9. A. DeJohn. The Comparison Between the Household and Person Category Trip Generation Models. State Univ. of New York, Buffalo, M.S. thesis, 1981.
10. K. Überla. Faktorenanalyse. Springer-Verlag, Berlin, New York, 1971.
11. J. Supernak, A. Talvitie, and B. Bogan. A Person Category Car Availability/Ownership Model. State Univ. of New York, Buffalo, Working Paper 782-17, 1981.
12. J. Supernak, A. Talvitie, and A. DeJohn. Transferability of the Person Category Trip Generation Model Between Baltimore and Twin Cities. State Univ. of New York, Buffalo, Working Paper 782-13, 1980.
13. J. Supernak. Transferability of the Person Category Trip Generation Model. Presented at the 9th Planning and Transport Research and Computation, Ltd. Summer Annual Meeting, Univ. of Warwick, Coventry, Warwickshire, England, 1981.
14. C.R. Fleet and A.B. Sosslair. Trip Generation Procedures: An Improved Design for Today's Needs. Traffic Engineering, Arlington, Va., Nov. 1976, pp. 17-25.
15. D.Y. Ashley. The Regional Highway Traffic Model: The Home-Based Trip End Model. Presented at the Planning and Transport Research and Computation, Ltd. Summer Annual Meeting, Univ. of Warwick, Coventry, Warwickshire, England, 1978.
16. A. Talvitie, M. Morris, and M. Anderson. An Assessment of Land Use and Socioeconomic Forecasts in the Baltimore Region. State Univ. of New York, Buffalo, Working Paper 782-04, 1980.

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