TIME-STABILITY ANALYSIS OF TRIP-GENERATION AND PREDISTRIBUTION MODAL-CHOICE MODELS

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Data from home-interview surveys in Detroit for 1953 and 1965 were used to test the time stability of disaggregate trip-generation and predistribution modal-choice models. Initial cross-classification analysis showed 4 to 18 percent increases in household trip-generation rates for households with cars available. A statistical test of the overall time stability of multiple linear regression trip-generation equations indicated that the equations were not stable unless non-trip-making households were removed. The individual regression coefficients also were tested for time stability, and, despite the lack of overall statistical time stability, disaggregate work- and home-based trip-generation equations for 1953 produced reasonable estimates of 1965 zone-level trips. Disaggregate regression equations for the automobile-driver and bus modes also were found to exhibit only limited time stability. Interaction between cars available and number of persons employed was particularly important in explaining bus trips. Tests of the time-stability assumption at the zone level were limited by the lack of zone-level interaction variables.

•THE CONVENTIONAL sequential models of urban travel demand (UTD models) require 3 basic assumptions for use in forecasting: (a) independent variables can be accurately forecast; (b) models provide an accurate, behaviorally correct simulation of base-year travel demand; and (c) model variables, structure, and parameters are stable over time (1). Early researchers in transportation planning were well aware of the need for accurate forecasts of independent variables. During the 1960s, considerable effort was devoted to developing sophisticated urban land use activity models to provide the required forecasts. Although the problem of producing accurate forecasts has proved more intractable than initially thought, the models can generate alternative land use patterns ranging from trend to normative statements of future development patterns such as centralization, radial corridors, or satellite development (2). The last 2 assumptions required for forecasting travel demand are closely related. Behavioral models that accurately predict base-year travel also should be valid in some future year. Deutschman (1), however, has argued that trip-generation models that produce a good fit for the base year nevertheless may fail completely when used for forecasting. Clearly, the goodness of fit of base-year data should not be the only criterion for model selection. Behavioral models are needed to provide not only time stability but also meaningful responses to changes in transportation systems, land use activity patterns, and socioeconomic conditions.

Considerable research has been devoted to developing better behavioral UTD models. Emphasis has focused on modal-choice models and, to a lesser extent, trip-generation models. Reported research, however, largely has ignored the other possible sources of error in forecasting travel demand. The attitude toward the accuracy of forecasts of independent variables appears to be that, if an independent variable is behaviorally

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significant, then some attempt should be made to forecast it. Roberts (3), however, has argued that, in view of the current difficulties in making accurate long-range forecasts of independent variables, the current UTD models are valid only for the short range. Such a view could also make time-stability errors relatively less important. If, however, the short range includes time periods of 5 to 10 years (which are not unreasonable periods for implementation of major transportation projects), time stability still may be an important criterion. Time-stability analyses have been limited by the lack of adequate time-series data. Even where data have been available for 2 or more time periods, operational pressures to produce travel demand forecasts as quickly and cheaply as possible generally have resulted in the use of only the latest data for model calibration and forecasting.

PURPOSE

The primary purpose of this research was to reevaluate the Detroit trip-generation model so that any new data requirements could be incorporated in the development of a new regional activity allocation model (4). The new data requirements also would provide a framework for an updating of the 1965 home-interview survey data by using 1970 census data.

In reevaluating the Detroit trip-generation model, emphasis was placed on developing a behavioral trip-generation model that would exhibit time stability. Because relatively consistent home-interview survey data were available for both 1953 and 1965, disaggregate trip-generation models were developed for both years and then were compared graphically and statistically for stability. Predistribution modal-choice models for both years also were developed to aid in understanding how changes in modal choice affect trip generation.

The substantial changes in population, residential density, and job location and in automobile ownership, household income, and level of service of the transportation system between 1953 and 1965 provided a significant test of trip-generation-model time stability. The sharp decline in transit use from 1953 to 1965 (16.2 percent of person trips by bus in 1953 versus 4.8 percent by bus in 1965) subjected the predistribution modal-choice model to an even more severe test of time stability.

RESEARCH METHODOLOGY

Household files with merged trip-record data for 1953 and 1965 were developed to be as nearly compatible as possible. The major limitation of the 1953 file was the lack of individual household income data. The 1953 variable, cars owned, was assumed to be equivalent to the 1965 variable, cars available; a compatible stage of life cycle variable was developed as a function of family size, age of youngest trip maker, and age of the head of the household. An additional limitation of the 1953 household file was the lack of complete data for variables obtained from the trip files. If no trips were made, then no data were available for these variables. Thus use of the trip file variables was limited to models for trip-making households.

A summary of the major independent and dependent variables that were compatible for 1953 and 1965 is given in Table 1. All but 1 of the variables that generally have been considered to be most significant in household-level trip-generation analysis are included (5, p. 96). The variable omitted is number of persons 16 years old or older who drive. One variable, AREA, requires some explanation. The AREA variable stratifies the region into 4 roughly concentric rings centered on the central business district (CBD): inner city, city center, suburbs, and rural area. The rural area is outside the 1953 study-area boundary; thus, no data are presented for this location. The AREA variable is a substitute for such variables as density, distance from CBD, and, to some extent, accessibility.

Recently, there has been considerable discussion of the desirability of including measures of the level of service provided by the transportation system at each stage of the urban transportation planning modeling process (6, 7). However, little empirical evidence exists to support the notion that transportation accessibility as currently measured is significant in explaining trip generation. For a household-level model Kannel (8, p. 116) concluded that "the effect of accessibility [to employment] on trip production rates would appear to be an indirect effect due to its influence on auto ownership." For zone-level models, both Nakkash (9) and Gur (10) found that accessibility variables contributed little to the explanatory power of the models. Nakkash (9) found that a simple stratification of zones into central and noncentral areas was more significant than inclusion of accessibility variables. The number of work trips is relatively inelastic with respect to accessibility or transportation cost. The level of non-work-trip making appears to be primarily a function of the number of automobiles available although the level of automobile ownership may be affected by transportation system accessibility, as shown by Kannel (8). Dunphy (11) has shown that automobile ownership also may be affected by transit accessibility to employment, thus holding 2 variables, income and family size, constant.

Multiple linear regression analysis was selected to develop trip-generation relationships for 1953 and 1965 because of the ease with which statistical measures of both goodness of fit and time stability can be obtained. Cross-classification techniques were used to examine the extent to which the data met the standard assumptions required for regression analysis. In addition, the automatic interaction detection program (AID) was used to identify potential interaction terms (12).

Four different approaches to trip-generation time-stability evaluation were used:

1. Graphical comparison,
2. Test of overall equality of regression-equation coefficients,
3. Test of equality of individual regression coefficients, and
4. Prediction of 1965 zone and district trips by using the 1953 equations.

The second approach used Chow's test for the equality of 2 sets of linear regression coefficients (13). In Chow's test of the equality of 2 sets of regression coefficients, the null hypothesis of equality of the regression coefficients for the 2 years (H_0: $\beta_1 = \beta_2$) is rejected at a ($1 - \alpha$) percent level of confidence if the test statistic F is greater than $F_{1-\alpha}$ with k and (m + n - 2k) degrees of freedom. F is computed

$$F = \frac{(Q_1 - Q_2)/k}{Q_2/(m + n - 2k)} \tag{1}$$

where

Q_1 = sum of squared errors from pooling the observations,
Q_2 = sum of squared errors from separate regressions for the 2 years,
m = number of observations in year 1,
n = number of observations in year 2, and
k = number of independent variables plus 1.

The practical application of the technique requires both a separate regression for each year and a regression on the pooled observations for both years. The difference between Q_1 and Q_2 provides a measure of the closeness of the 2 sets of regression coefficients. If the regression equations are identical, the difference between Q_1 and Q_2 will be 0.

The third approach used the time interval as a dummy variable to test each regression coefficient for change over time. The time-period dummy variable T is included as an interaction term with every independent variable, including the constant term. For example, the regression equation

$$HB = a_0 + a_1CARA + a_2NRES \qquad (2)$$

becomes

$$HB = a_0 + b_0T + (a_1 + b_1T)CARA + (a_2 + b_2T)NRES \qquad (3)$$

where each interaction term has been combined with its respective independent variable. The coefficient of each independent variable is tested for time stability under the null hypothesis that the interaction term regression coefficient b_i equals 0 (H_0: $b_i = 0$).

Identical analyses were used to develop predistribution modal-choice models and evaluate their time stability. Considerable attention was given to the development of appropriate interaction terms.

TRIP-GENERATION MODEL DEVELOPMENT

Primary emphasis was placed on developing trip-generation equations for TTF, HB, and WK. Equations also were developed for PB, SR, and SHOP trip purposes.

The 2 types of independent variables found to be most important in explaining total trip generation were (a) some measure of household size and (b) some measure of household economic status. The available household-size variables for the Detroit area were LC, NRES, and FIVE. CARA was the only economic variable available for both years. The impact of INC, however, could be analyzed at the household level for 1965. EMP was important for explaining work trips. The other available variables given in Table 1 also were evaluated for significance in explaining the various trip purposes.

An initial cross-classification analysis provided an indication of the extent to which the standard assumptions required for regression analysis were met as well as a graphical measure of the degree of time stability. The cross-classification of TTF by CARA and NRES for both 1953 and 1965 (Figure 1) showed relatively consistent change over time. The mean daily trip rates for household-size classes with 1 or more cars available were approximately 10 percent greater in 1965 than in 1953. (The actual range was 4 to 18 percent; the increase for the individual car-available classes ranged from 1 to 9 percent.) The relatively uniform upward shift suggests an additional income effect or a uniform regional increase in accessibility. A shift from neighborhood walk trips (no data available) to vehicle trips for shopping, social-recreational, and similar purposes also might have contributed to the increase.

In contrast, households in each household-size class with no cars available made approximately 20 percent fewer trips in 1965 than in 1953. The no-car-available class in 1965 was composed primarily of poor and elderly people, many of whom reported not making any trips. Underreporting of trips also might be more of a problem here.

When non-trip-making households were removed, the difference in trip making between 1953 and 1965 for the household-size classes with no cars available was reduced from a 20 percent decline to a range of -3.9 to +8.7 percent change. Almost all households with 1 or more cars available made trips. Thus little change in the trip rates of the 1- and 2-cars-available classes as a function of NRES occurred when non-trip-making households were removed. Further stratification by AREA of the CARA versus NRES curves for trip-making households showed a generally higher level of suburban (AREA = 3) trip making and a lower level of inner city (AREA = 1) trip making in 1965. Trip making by city center residents (AREA = 2) remained relatively constant. Figure 2 shows the relationships for a family of 4 (NRES = 4).

Cross tabulation of home-based WK for both years by EMP and CARA showed the expected essentially constant rate of WK/person employed. To expect WK generation to be independent of INC and CARA is reasonable. There should also be little change over time unless, for example, the 4-day work week were to be adopted widely.

Table 1. Household variables.

Variables	Designation
Independent	
Cars available, 1965	CARA
Cars owned, 1953[a]	CARA
Income[b]	INC
Stage in the family life cycle	LC
Number of household residents[a]	NRES
Number of persons 5 years old and older[a]	FIVE
Number of persons employed	EMP
Race of household head	RACE
Type of structure (single or multiple)[a]	STR
Occupation of household head	OCC
Sex of household head	SEX
Labor force status of household head	LF
Age of youngest trip maker	Y
Location in the region[a]	A1, A2, A3, A4
Small area location[a]	ZONE
Dependent	
Total factored person trips	TTF
Total home-based person trips	HB
Work trips	WK
Personal business trips	PB
Social and recreational trips	SR
Shopping trips	SHOP

[a] Available for all households in 1953.

[b] Available only at the census tract level for 1953.

Figure 1. Household trip rates.

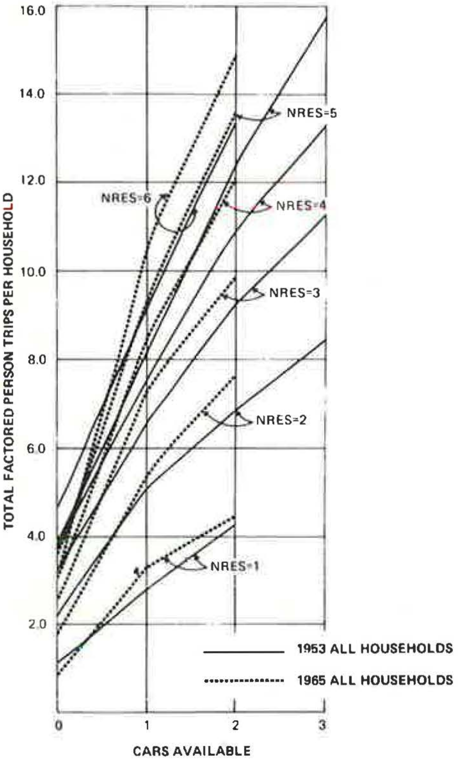
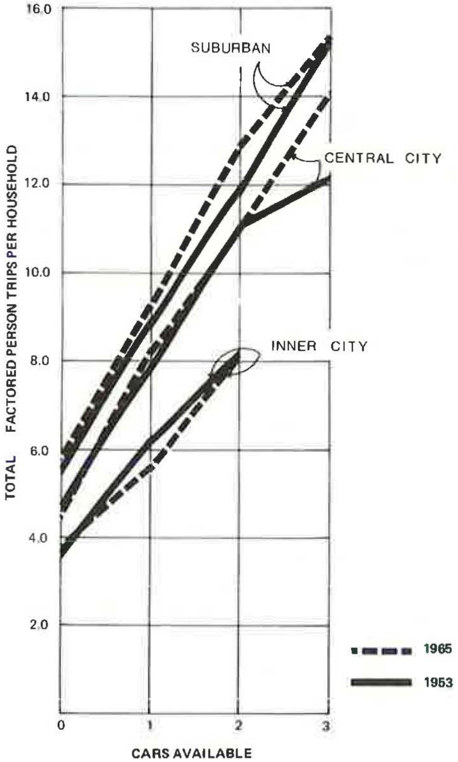


Figure 2. Trip rates for trip-making households with 4 residents.



The linearity assumption required by regression analysis (unless dummy variables are used) appears to be generally satisfied for the TTF trip relationships so that little advantage would be obtained from using dummy variables for CARA or NRES. The main restriction on the regression analysis appeared to be the lack of normal error terms with constant variance. The distributions of the dependent variables were skewed, which indicates that the distributions of the error terms probably were not normal. Also the variance of the dependent variables tended to increase with the independent variables, which indicates heteroscedastic error terms. Similar results have been reported by Oi and Shuldiner (14) and Kannel (8). Thus the statistical reliability of the significance tests on the regression coefficients is likely to be overstated.

The graphical cross-classification analysis indicated that the additivity assumption required for regression analysis generally was satisfied. There was little evidence of interaction among the independent variables. More detailed analysis of interaction by using the AID program confirmed the assumption of negligible interaction.

Household-level trip-generation regression equations were developed for both years by using a systematic 1-in-8 sample of the more than 40,000 households in both the 1953 and 1965 household files to reduce computing costs (Table 2). The analysis was concentrated on the home-based-trip purpose because home-based trips provided the control total for the individual home-based-trip purposes in the 1965 Detroit trip-generation model. Selecting a household-size variable for the HB-FIVE equation resulted in a slightly higher coefficient of determination r^2 than for the HB-NRES equation. However, for forecasting purposes NRES probably would be better because it is available in the 1970 census transportation planning package. LC provided greater explanatory power than did either NRES or FIVE. However, even if LC were available for all households, the potential error in forecasting it probably would outweigh the improvement in base-year accuracy. The AREA variable was significant for the home-based equation but not for the work or personal-business equations.

The trip-generation equations for trip-making households only were developed by using the same independent variables as were used in the all-households equations. The coefficients of NRES were essentially the same as for the comparable all-households equation; however, the constant terms and the coefficients of CARA changed substantially. The trip-making-only equations exhibited consistently lower coefficients of determination than did the all-households equations.

TIME-STABILITY EVALUATION

Test of Overall Stability

The results of the test of the null hypothesis of no difference in the trip-generation equation regression coefficients (H_0: $\beta_{53} = \beta_{65}$) are given in Table 3. Only 2 equations were concluded to be stable at the 1 percent level of significance—the HB equation for trip-making households only with CARA and NRES as independent variables and the SR equation for all households with CARA, NRES, and AREA as independent variables. Even these 2 equations were not stable at the 5 percent level of significance. Thus the statistical analysis indicates that, in general, the overall differences in trip-generation rates that were observed both in the graphical analyses and in the comparison of the individual regression equations for the 2 years are statistically significant.

Test of Regression Coefficient Stability

The test of the time stability of the individual regression coefficients confirmed the results of the overall time-stability analysis for the home-based purpose (Table 4). The constant term was found to change over time (at the 1 percent level) for all of the HB equations except the trip-making-households-only equation with CARA and NRES as independent variables. The results for the individual home-based-trip purposes (WK, PB, SR, and SHOP), however, showed that stability of each of the coefficients in an trips are available from government or private data sources.

2. A trip-distribution model for small- and medium-sized urban areas can be calibrated by using available trip-end information.
3. The necessary information for traffic planning, the average daily traffic and the peak-hour volumes, can be deduced from the home-based work trips.

GRAVITY-DISTRIBUTION MODEL FOR SMALL- AND MEDIUM-SIZED URBAN AREAS

Following Evans (3) and Sasaki (9), one can write a 2-way, constrained gravity model as

$$T_{ij} = r_i s_j F(C_{ij}) \tag{1}$$

where

T_{ij} = number of trips originated from zone i and destined to zone j as predicted by a 2-way gravity model;
$F(C_{ij})$ = distribution (impedance) function, which is a function of the travel cost C_{ij}; traditionally, travel cost is expressed in minutes of travel time; and
r_i and s_j = normalization factors established so that trip productions and trip attractions predicted by the gravity model become equal to the original trip productions and attractions (definition of a 2-way, constrained gravity model).

Therefore, r_i and s_j are solutions of the following equations:

$$\sum_j r_i s_j F(C_{ij}) = P_i \tag{2}$$

$$\sum_i r_i s_j F(C_{ij}) = A_j \tag{3}$$

which also satisfy

$$\sum_i \sum_j r_i s_j F(C_{ij}) = T \tag{4}$$

where

P_i = trip production of zone i,
A_j = trip attraction of zone j, and
T = total trip exchange within the system.

This notation of the gravity model is basically the same as the conventional use of the 2-way, constrained gravity model (3). In the conventional use, trip attractions are iteratively changed for meeting the trip end constraints; in this notation, the normalization factors r_i and s_j are iteratively set to meet these constraints. This notation is being used in this paper only for clarification. The distribution function quantified for equation 1 can be used for the conventional use of the gravity model without any change.

Table 2. Trip-generation equations.

Households	Year	Regression Equation[a]	r^2	Standard Error	Mean
All[b]	1965	HB = -0.65 + 2.43CARA + 0.93NRES	0.355	3.93	5.61
	1953	HB = 0.11 + 2.02CARA + 0.81NRES	0.276	3.42	4.72
	1965	HB = -0.84 + 2.30CARA + 1.14FIVE	0.377	3.86	5.61
	1953	HB = -0.29 + 1.82CARA + 1.13FIVE	0.314	3.33	4.72
	1965	HB = -1.41 + 2.20CARA + 0.93NRES + 0.76A2 + 1.48A3	0.364	3.90	5.61
	1953	HB = -0.31 + 1.87CARA + 0.80NRES + 0.67A2 + 0.89A3	0.282	3.41	4.72
	1965	WK = +0.08 + 1.63EMP	0.582	1.01	1.82
	1953	WK = -0.06 + 1.65EMP	0.582	1.05	2.01
	1965	PB = -0.18 + 0.62CARA + 0.18NRES	0.102	1.97	1.21
	1953	PB = -0.07 + 0.46CARA + 0.11NRES	0.069	1.43	0.72
Trip making only[c]	1965	HB = +0.17 + 2.10CARA + 0.92NRES	0.272	4.02	6.40
	1953	HB = +0.90 + 1.84CARA + 0.76NRES	0.233	3.38	5.39
	1965	HB = -0.81 + 1.87CARA + 0.92NRES + 1.01A2 + 1.68A3	0.283	3.99	6.40
	1953	HB = +0.47 + 1.69CARA + 0.75NRES + 0.63A2 + 0.91A3	0.240	3.36	5.39
	1965	WK = +0.20 + 1.59EMP	0.534	1.03	2.08
	1953	WK = -0.04 + 1.66EMP	0.501	1.09	2.30

[a] All coefficients are significant at the 1 percent level.
[b] Sample size: 2,586 for 1965 and 2,529 for 1953.
[c] Sample size: 2,265 for 1965 and 2,216 for 1953.

Table 3. Summary of overall time-stability test, $H_0 : \beta_1 = \beta_2$.

Dependent Variable	Independent Variables	r^2		Degrees of Freedom	F (ratio of mean standard error)
		1965	1953		
HB	CARA, NRES	0.355	0.276	3	5.22
HB	CARA, NRES, A2, A3	0.364	0.282	5	4.68
HB	CARA, FIVE, A2, A3	0.388	0.322	5	4.20
HB[a]	CARA, NRES	0.272	0.233	3	3.65[b]
HB[a]	CARA, NRES, A2, A3	0.283	0.240	6	3.51
WK[a]	EMP	0.534	0.501	2	11.9
WK	EMP	0.582	0.582	2	8.36
PB	CARA, NRES, A2, A3	0.108	0.070	5	10.46
SR	CARA, NRES, A2, A3	0.115	0.085	5	2.83[b]
SHOP	CARA, NRES, A2, A3	0.110	0.082	5	5.99

[a] Includes trip-making households only.
[b] Stable at 1 percent level.

Table 4. Summary of regression slope and intercept stability.

Households	Regression Equation
All	HB = 0.11 - 0.76T + (2.03 + 0.41T)CARA + (0.81 + 0.12T)NRES t values = 3.03[a] 17.3 2.67[a] 16.2 1.80
All	HB = -0.30 - 1.11T + (1.87 + 0.33T)CARA + (0.80 + 0.13T)NRES + (0.67 + 0.09T)A2 + (0.89 + 0.59T)A3 t values = 3.45[a] 15.4 2.06 16.0 1.96 3.35 0.27 4.36 1.84
All	HB = -0.75 - 0.92T = (1.64 + 0.39T)CARA + (1.12 + 0.02T)FIVE + (0.69 + 0.11T)A2 + (0.98 + 0.61T)A3 t values = 2.93[a] 13.6 2.52 19.8 0.27 3.51 0.34 4.94 1.97
Trip making only	HB = 0.92 - 0.75T + (1.84 + 0.26T)CARA + (0.75 + 0.16T)NRES t values = 2.52 15.4 1.56 14.1 2.30
Trip making only	HB = 0.50 - 1.31T + (1.69 + 0.18T)CARA + (0.74 + 0.17T)NRES + (0.62 + 0.39T)A2 + (0.91 + 0.78T)A3 t values = 3.46[a] 12.8 1.04 13.9 2.46 2.80 1.06 4.02 2.18
All	WK = -0.06 + 0.14T + (1.65 - 0.02T)EMP t values = 2.67[a] 60.6 0.56
All	PB = -0.07 - 0.11T + (0.46 + 0.16T)CARA + (0.11 + 0.07T)NRES t values = 0.97 8.33 2.27 4.54 2.38
All	SR = -0.35 - 0.24T + (0.44 - 0.10T)CARA + (0.18 + 0.11T)NRES + (0.36 - 0.15T)A2 + (0.45 + 0.06T)A3 t values = 1.47 7.01 1.22 6.96 3.19[a] 3.42 0.90 4.29 0.35
All	SHOP = -0.24 - 0.17T + (0.28 + 0.07T)CARA + (0.12 + 0.04T)NRES + (0.21 + 0.12T)A2 + (0.46 + 0.21T)A3 t values = 1.33 5.67 1.05 5.94 1.57 2.58 0.92 5.61 1.67

[a] Significant at the 1 percent level and therefore unstable.

equation does not guarantee the overall time stability of the equation. Neither the PB nor the SHOP equation had any unstable coefficients, yet neither equation exhibited overall time stability. In contrast, the SR equation exhibited overall time stability, but the coefficient of the independent variable NRES changed over time. The results of this test should not be overemphasized because the assumptions required for multiple linear regression analysis were not analyzed for the individual home-based-trip purposes.

Application of the Zone Level

The final test of the time stability of the regression equations was to forecast 1965 zone trips by using the equations developed for 1953. The 1953 HB trip-generation equation with CARA, NRES, and AREA as independent variables was applied to 1965 zone-level data. The resulting estimates of 1965 zone HB trips were reasonable (r^2 for actual versus estimate was 0.950). The 1965 zone estimates produced by the comparable 1965 HB equation were only slightly more accurate than those produced by the 1953 HB equation (Figure 3). When stratified by AREA, the 1953 HB equation (and probably the 1965 HB equation as well) was more accurate for estimating the city center and suburban areas than it was for the inner city and rural areas, which indicates that additional study of the latter 2 areas is needed.

Comparison With Other Urban Areas

Ideally, household-level trip-generation regression equations developed in one urban area also should be valid for other urban areas. Comparison of home-based trip-generation equations for urban areas ranging in size from 250,000 (Madison, Wisconsin) to more than 14,000,000 (New York City) shows substantial variations in the regression coefficients although the same independent variables are significant for all of the U.S. cities (Table 5). Part of the variation may be attributed to differences in data collection and definitions of the variables. The wide variation in the CARA coefficients also may be the result of differences in transit service and household income. There is relatively little variation in the FIVE coefficient. Madison, Wisconsin, may be a special case because of the large college-student population.

A comparison of household-level regression equation slope and intercept stability between Pittsburgh and Detroit shows generally similar results although the magnitude of individual regression coefficients differs substantially (Table 6). The slopes for the SHOP equation are stable (at the 1 percent level), and slopes for the TTF equation are generally unstable. The independent variables for other purposes in the Pittsburgh study were not compatible with the Detroit variables.

PREDISTRIBUTION MODAL-CHOICE ANALYSIS

The 2 most important trip purposes, home based and work, were analyzed for both the automobile-driver and bus modes. In contrast to the person-trip-generation relationships, the AID analysis indicated significant interactions between the 2 primary independent variables for the bus mode—CARA and EMP. The subsequent cross-classification analysis of the bus purposes indicated that the interaction variable, EC, which is defined as the nonnegative difference between the number of employees in the home and the number of cars available, that is,

$$EC = \begin{cases} (\text{EMP} - \text{CARA}) \geq 0 \\ 0 \quad \text{otherwise} \end{cases}$$

should be a good predictor of bus-work and bus-home-based trips. A graphical analysis of the stability of the bus-work trip relationships is shown in Figure 4. As expected, a generally lower level of transit use is observed in 1965.

Statistical analysis of the bus-work and bus-home-based regression equations for trip-making households indicated that none of several sets of independent variables provided overall time stability. When only households with convenient access to transit were considered (households in the bus service area), however, stable relationships for both the work and the home-based bus purposes were found with EC and AREA as dummy variables. The individual regression coefficients also were found to be stable for both equations. Additional research is needed to evaluate the feasibility for forecasting EC. EC is likely to be a complex function of the income level and the level of transit service.

As for the bus purposes, the AID analysis for the automobile-driver purposes indicated interaction between CARA and EMP. Subsequent cross-classification analysis indicated that the interaction variable, CE, defined as the nonnegative difference between CARA and EMP

$$CE = \begin{cases} (CARA - EMP) \geq 0 \\ 0 \quad \text{otherwise} \end{cases}$$

should be a good predictor of automobile-driver trips. CE was significant as an explanatory variable for both automobile-driver-WK and automobile-driver-HB regression equations; however, neither equation exhibited overall stability for the entire region. Within the bus service area the automobile-driver-HB equation with CARA, FIVE, and AREA as independent variables exhibited overall stability. The individual regression coefficients also were stable.

Application of the bus-purpose equations to estimate zone bus trips was limited by the lack of interaction variables at the zone level. Reasonable estimates of zone trips for the 2 automobile-driver purposes, however, were obtained. The error curves (cumulative percent of zones versus percentage of error in the zone estimate) were virtually identical to the error curves for person-trip purposes, which is reasonable when one considers the low level of transit use in Detroit.

CONCLUSIONS

Cross-classification analysis of 1953 and 1965 total person-trip generation as a function of cars available and number of persons in the household showed unexplained differences in the trip-generation rates of 10 to 20 percent. The largest differences were observed in the no-car-available class. Thus, when non-trip-making households (which were concentrated in the no-car-available class) were removed, the resulting regression equation was concluded to be stable.

The relatively uniform increase in trip rates for all automobile-owning household-size classes probably is due to changes in income, regional accessibility, and the level of walking trips. Additional time-series data are needed to evaluate the impact of these variables. In the absence of such time-series data, the disaggregate trip-generation relationships for 1965 and 1953, as shown by the zone-level estimates, can provide an upper and a lower bound for reasonable estimates of future trip generation in Detroit.

The high degree of explanatory power of the work-trip-generation equation suggests that peak-hour UTD models based on work trips should be developed for Detroit. The lack of time stability probably was due primarily to differences in defining the employment variable between 1953 and 1965 rather than any inherent change in the level of work-trip making. Peak-hour models would be particularly useful because data are available from the 1970 census transportation planning package on work-trip and employment patterns. Thus the updating of the 1965 travel survey data is provided for.

The predistribution modal-choice analysis indicates the importance of the joint consideration of the number of persons employed and the number of cars available at the

Figure 3. Zone test of time stability.

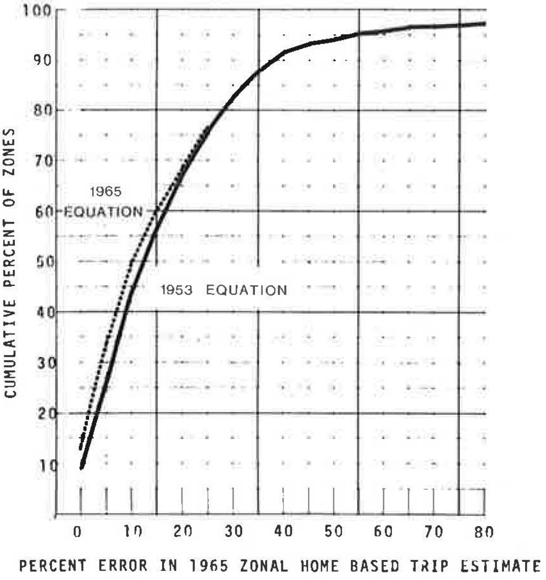


Table 5. Comparison of household-level home-based trip-generation equations for several urban areas.

Urban Area	Year	Regression Equation	r^2	Standard Error	Mean
Madison, Wisconsin (5)	1962	HB = 0.69 + 1.94CARA + 1.39FIVE	0.36	3.89	5.20
Glamorgan, Wales (15)	—	HB = 0.91 + 1.07CARA + 1.07EMP	0.384	2.33	—
New York City (16)	—	HB = 0.24 + 3.17CARA + 1.06FIVE	0.309	5.03	5.87
Indianapolis (8)	1964	HB = -0.19 + 3.17CARA + 1.15FIVE	—	—	—
Detroit	1965	HB = -0.84 + 2.30CARA + 1.14FIVE	0.377	3.86	5.61
Detroit	1953	HB = -0.29 + 1.82CARA + 1.13FIVE	0.314	3.33	4.72

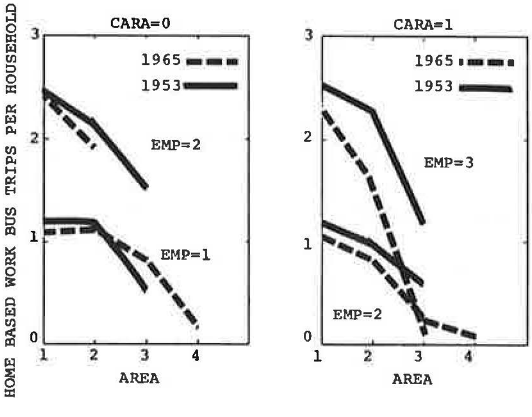
Table 6. Comparison of trip-generation slope and intercept time stability for Pittsburgh and Detroit.

Urban Area[a]	Regression Equation	r^2	Standard Error	Mean
Pittsburgh (17)	SHOP = 0.18 + 0.51T + (0.33 - 0.27T)CARA + (0.08 - 0.01T)NRES t values = 2.63[b] 2.11 0.11	0.030	—	—
Detroit	SHOP = -0.07 + 0.0T + (0.36 + 0.10T)CARA + (0.13 + 0.04T)NRES t values = — 7.51 1.60 6.26 1.37	0.097	1.50	0.88
Pittsburgh (17)	TTF = 1.66 + 1.82T + (2.00 - 0.38T)CARA + (0.57 - 0.69T)NRES t values = 3.44[b] 1.10 2.81[b]	0.208	—	—
Detroit	TTF = 0.16 - 1.26T + (3.13 + 80T)CARA + (0.98 + 0.29T)NRES t values = 3.06[b] 16.3 3.20[b] 12.0 2.69[b]	0.289	6.05	7.33

[a] Pittsburgh data are for 1958 and 1967. Detroit data are for 1953 and 1965.

[b] Significant at the 1 percent level.

Figure 4. Bus-work-trip time stability for households with no car and 1 car available.



household level in explaining transit use, particularly for work trips. In Detroit, significant transit use generally occurs only for households in which the number employed exceeds the number of cars available. Thus short-term transit service improvements are not likely to attract workers who have a car available. Over a longer time period, however, the introduction of competitive transit service may result in a decision not to replace the second car or not to buy a car when a family member joins the labor force.

ACKNOWLEDGMENT

We would like to thank the Southeast Michigan Council of Governments for making this research possible. Much of the research reported here was conducted as part of Robert L. Smith's doctoral research program in civil engineering at the University of Michigan (18).

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