Long-Range Temporal Stability of Trip Generation Rates Based on Selected Cross-Classification Models in the Delaware Valley Region

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Results of a comparative trip generation rate analysis between a home interview survey conducted in the Delaware Valley region in 1987–1988 and the original 1960 survey are summarized. Selected stratification schemes based on combinations of trip purpose, family size, income, automobile ownership, and area type are tabulated and analyzed with cross-classification techniques to determine the impact of these input variables on the temporal stability of household trip generation rates. The selection of variables used in the cross-classification scheme affected the temporal stability of the resulting trip generation model. Household size stratifications were generally temporally unstable, income-based models more stable, and automobile ownership strata the most stable over time. A trip generation model based on appropriate cross-classifications by automobile ownership or area type, or both, produced reasonably stable trip generation results by trip purpose and when estimating total household travel.

Results of a comparative trip generation rate analysis between a home interview survey conducted in the Delaware Valley region in 1987–1988 and the original 1960 survey conducted by the Penn Jersey Transportation Study, precursor agency of the Delaware Valley Regional Planning Commission (DVRPC), are summarized. Selected stratification schemes based on trip purpose, family size, income, automobile ownership, and area type are tabulated and analyzed with cross-classification techniques to determine the impact of these input variables on the temporal stability of trip generation rates.

These variables were selected because they are determinants of trip making and for this reason are commonly used in regional trip generation models. Structure type, another variable often used, was not available for this analysis, but area type (i.e., central business district, urban, suburban, and rural) is largely a substitute. A discussion of the relative merits of each variable in cross-section analysis (for a single year) is provided by McDonald and Stopher (*1*) and Walker and Olanipekun (*2*).

Published results from the 1960 survey documented the short-run stability of trip generation models based on regression equations, the standard modeling technique at that time. Kannel and Heathington (*3*) reported that a linear regression model calibrated with 1964 household data from the Indianapolis region was able to reproduce the behavior of the same households when a small subsample of these households was reinterviewed in 1971. This model included family size and automobile ownership as independent variables but did not include trip purpose. The distribution of family sizes was stable, but automobile ownership increased significantly over this period. Similar results with regional regression equations based on land use and trip purpose were reported by Yunker (*4*) for the southeastern Wisconsin region for the period between 1963 and 1972.

The medium- to long-range stability (1965–1981) of two-dimensional cross-classification rate structures based on trip purpose versus household size, automobile ownership, and income was analyzed for the San Francisco Bay Area by Kollo and Purvis (*5*). They found that significant intertemporal changes in trip rates for a given socioeconomic strata were counterbalanced by shifts in the distribution of households between strata. As a result, total household trip generation rates did not change significantly.

Another approach to the evaluation of the temporal stability of trip generation behavior involves detailed factor analysis of variables thought to influence travel behavior. If the relative statistical importance of these variables changes over time, then the corresponding trip generation model may be unstable. Kitamura and Kostyniuk (*6*) present an analysis of changes in the relative importance of a number of household variables on the trip generation behavior measured in 1963 and 1974 home interview surveys for Rochester, New York. These factors include household size, income, the number of workers and drivers, automobile ownership (excluding zero-car households), and household life-cycle stage (i.e., age of adults and presence and age of children). On the basis of analysis of variance (ANOVA) techniques, it was concluded that the effect of automobile ownership has declined and that life-cycle stage has more influence on household travel behavior. Although focused on measures of statistical influence and significance rather than on actual rates, this study seems to indicate that trip generation rates in the higher automobile ownership categories, and perhaps overall trip rates, have declined over time. Lave (*7*) also predicts a leveling off of trip generation rates because of a growing saturation of the demand for automobiles, a stabilization of labor force participation rates especially among women, and the aging of the American population.

The 1980s were a decade of rapid growth in automobile travel, brought on by decentralization of population and em-

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ployment out of the urban core, abundant supplies of inexpensive gasoline, and large increases in automobile ownership. It is interesting to analyze the stability of trip generation rates over a long-range time interval that includes this decade.

SURVEY DATA AND STATISTICAL ANALYSIS METHODS

The 1987–1988 survey consisted of 2,424 telephone household interviews. The New Jersey portion (887 interviews) was collected during October and November 1987. The Pennsylvania counties (1,537 interviews) were surveyed during the same months in 1988. Although the interviews were conducted by different consultants, the data forms and interviewing techniques for the two groups were essentially the same. This 1987–1988 survey covered the entire nine-county DVRPC region (see Figure 1). The overall sample rate was 0.13 percent of the 1,847,000 households in the region; the rate varied somewhat by county, with the smallest rate (but the greatest number of interviews) in Philadelphia (0.075 percent) and the largest rate in Burlington County (0.20 percent). The survey was controlled by county and automobile ownership. An effort was made to reach zero-car, low-income households; however, the survey failed to achieve a completely representative sample from this group even after a supplemental contract with the consultant.

The Penn Jersey home interview survey consisted of 56,100 in-person household interviews conducted between June and November 1960. This survey also sampled dense urban areas at a lower rate than more sparsely settled suburban and rural areas. A uniform sampling rate of 4 percent was used in Philadelphia and Camden counties and in densely settled suburban areas. A rate of 10 percent was used in lower-density areas and in Mercer County. This survey was confined to the Penn Jersey study area, also shown in Figure 1.

The survey forms used in the 1960 and 1987–1988 surveys were compatible, with similar demographic information collected and the same categories used for trip purpose and travel mode. Identical trip linking procedures were used to eliminate change-mode and serve-passenger trips. Household income presented a minor problem in that meaningful comparisons require the use of constant (1988) dollars. The high cost of living index (320.2) required to translate 1960 dollars to current dollars caused some mismatches between the income categories of the two surveys. These income range overlaps were resolved for the most part by combining detailed categories.

The method used to compare the trip generation rates implicit in the 1987–1988 survey with those in the Penn Jersey survey is known as the cross-classification technique. This method is similar to the widely used multiple regression technique in that changes in trip rates are measured while changes in two or more independent variables are accounted for. In this case, however, an n dimensional matrix of mean or average trip rates is calculated whereby each variable (trip purpose, automobile ownership, area type, income, etc.) has at least two subcategories defined by contiguous ranges of the appropriate variable. Cross-classification analysis is inherently disaggregate in that rates are tabulated directly from household data rather than relying on zonal averages of trip rates or independent variables.

Trip rates from both surveys were based on unfactored household data to make the results comparable. The Penn Jersey survey records included a composite final trip factor based on the inverse of the sample rate and on the results of a screenline analysis that compared surveyed trip crossings with traffic counts. This screenline analysis determined that about 78 percent of total travel was recorded in the trip diaries, with the remainder unreported. The 1987–1988 survey could not be factored with screenline analysis because of the small sample rate. Because of the similarity of survey forms

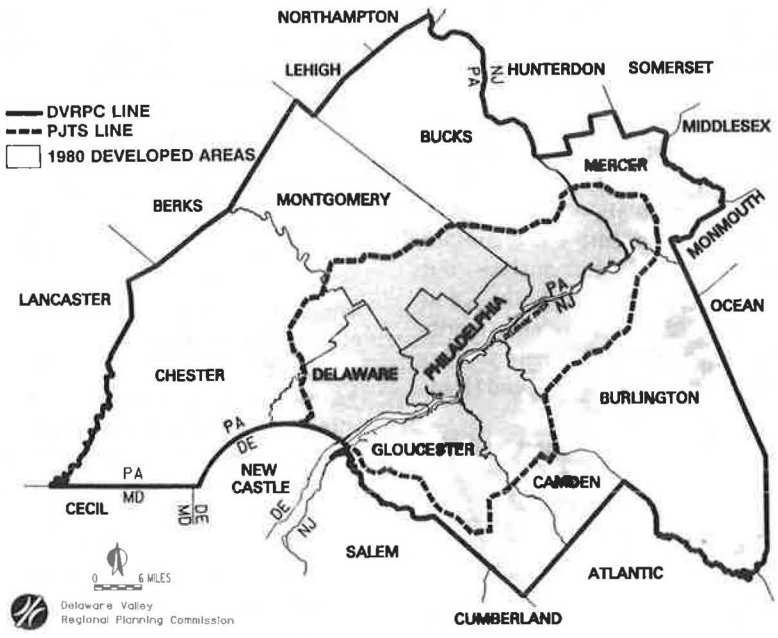

FIGURE 1 Penn Jersey transportation study and DVRPC regional cordon lines.

and data collection and processing techniques, it was assumed that the degree of trip underreporting is the same in both surveys.

The Penn Jersey survey data files only included travel internal to the Penn Jersey cordon area shown in Figure 1. For comparability, the 1987–1988 survey was also tabulated on this basis, unless indicated otherwise. This cordon line convention results in trip rates that are somewhat lower than those found through the more usual practice of tabulating all trips that are recorded on the trip diary.

Three statistical indicators are calculated for each trip rate cell in the cross-classification matrix: (a) the mean or average trip rate for households within that strata, (b) the number of observations, and (c) the cell standard deviation. The primary output is the cell mean trip rate. The number of observations in the cell and its standard deviation provide statistical measures of the accuracy of the rate (via confidence interval) and facilitate hypothesis tests on the difference between rates from each survey. The *t*-test of the statistical significance of differences between two mean trip rates is based on the idea that the hypothesis that trip rates differ must be rejected if their confidence intervals overlap. For this test to be valid, a sufficient number of observations must be available in each cell—at least 25 for practical purposes. This *t*-test does not directly measure the absolute magnitude of rate differences. A poor model with large standard deviations about the mean rates in each cell will have a greater tendency to be statistically stable than a more precise model with the same absolute rate differences.

Although more nebulous and difficult to define, rate differences may also be categorized in terms of planning significance. Planning significance relates to the magnitude of the difference more than to its statistical significance. For this reason, selected tables also contain estimates of percent difference between rates so that any logical patterns of these differences may be identified. A difference of 1 percent may be statistically significant, if the sample is large enough and the mean is tightly constrained by the cell standard deviation. This difference is of little planning significance, however. A difference of 10 percent or more was somewhat arbitrarily defined as being of planning significance, particularly if this difference is part of a logical overall pattern of trip rate variation. Because most studies ultimately use trip generation model results to produce travel volumes on transportation facilities, it is the total travel estimate rather than the estimates by trip purpose or socioeconomic strata that have real planning significance.

Table 1 presents a comparison of 1960 and 1987–1988 aggregate household trip rates stratified by trip purpose. Clearly, household trip making has increased significantly during this time period. Overall, household trip rates have increased by almost 25 percent. Home-based work trips have declined by about 10 percent, whereas home-based nonwork and non-home-based travel have increased by 33 and over 100 percent, respectively. These shifts may be interrelated and reflect survey tabulation conventions as well as trip-making decisions. For instance, a stop at a convenience store on the way home from work creates a non-home-based trip from work to shopping and a home-based shopping trip to reach home. These two trips replace the single home-based work trip recorded in the 1960 survey. In 1960, transit was a much bigger factor in work travel, and convenience stores were less common. However, this phenomenon does not completely explain the large increases in Table 1. Overall household trip generation rates seem to have increased significantly as a result of the automobile-oriented suburban life styles that have become much more prevalent since 1960.

The data in Table 1 must be interpreted carefully because aggregate regional trip rates are valid only if the sampled population reflects the distribution of demographic and economic characteristics in the regional population. Table 2 presents a comparison of the socioeconomic characteristics of the 1960 and 1987–1988 samples with those recorded in the 1980 census. From this table, it appears that the aggregate trip rates from the 1987–1988 survey may have been somewhat overestimated because of an underrepresentative sample of zero-auto, single-person households with incomes under $10,000. It is difficult to reach this type of household with telephone interviewing techniques. These aggregation problems largely disappear, however, when trip rate comparisons

TABLE 1 COMPARISON OF HOUSEHOLD TRIP RATES STRATIFIED BY DETAILED TRIP PURPOSE

TRIP PURPOSES	1960	1987-88	DIFF.	PCT.DIFF	"t" VALUE
Home-Based Work	1.86	1.66	-0.20	-10.75	4.96*
Home-Based Non-Work	2.12	2.82	0.70	33.02	9.04*
Home-Based Shopping	0.68	0.92	0.24	35.29	6.86*
Home-Based Social Rec.	0.77	0.52	-0.25	-32.47	5.84*
Home-Based Person Bus.	0.51	0.74	0.23	45.10	7.47*
Home-Based Eat Meal	0.01	0.24	0.23	2300.00	44.27*
Home-Based Other	0.15	0.39	0.24	160.00	11.93*
Home-Based School	0.41	0.41	0.00	0.00	0.17
Total Home Based	4.40	5.20	0.80	18.18	8.02*
Non-Home Based	0.64	1.35	0.71	110.94	16.55*
TOTAL	5.03	6.25	1.22	24.25	9.96*

* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 2 SOCIOECONOMIC CHARACTERISTICS OF THE 1960 AND 1987–1988 SURVEY SAMPLES

	1960 Survey	1980 Census	1987-88 Survey
Autos per Household	**0.89**	**1.26**	**1.61**
% of Households			
0 Auto	26.5%	20.3%	10.8%
1 Auto	54.8	42.8	34.7
2 Autos	16.6	29.1	40.3
3+ Autos	2.1%	7.8%	14.2%
Persons per Household	**3.36**	**2.87**	**2.67**
% of Households			
1 Person	12.5%	22.7%	18.4%
2 Persons	26.0	29.3	34.2
3 Persons	19.6	17.5	18.5
4 Persons	19.7	15.6	17.3
5 Persons	11.9	8.6	7.9
6 Persons	10.3%	6.3%	3.7%
Av. Household Income*	**$20,100**	**$31,000**	**$39,400**
% of Households			
Under $10,000	15.3%	21.3%	7.5%
$10,000 - $19,999	48.7	20.0	16.4
$20,000 - $29,999	26.3	13.9	18.3
$30,000 - $49,999	6.6	29.8	31.4
$50,000 - $69,999	2.1	9.9	15.6
Over $70,000	1.0%	5.1%	10.8%

* 1988 Constant Dollars

are cross-classified with these socioeconomic variables. The principal concern then is to obtain a statistically sufficient number of observations within each cell of an appropriate cross-class matrix.

The school trip rates exclude trips made by primary- and secondary-school students in district-sponsored (yellow) school buses. Only automobile and public transit school trips are included. None of the trip purposes include walk or bicycle travel. Also, the trip rates given in Table 1 only consider travel that is internal to the Penn Jersey study cordon line. By comparison, the 1987–1988 household trip rate for the total of all trip purposes increases from 6.25 to 7.33 when the cordon is expanded to DVRPC's nine-county region. The total household trip rate for the 1987–1988 survey (for the nine-county region) is 7.79 trips per household when all external-local travel is included.

TEMPORAL STABILITY OF SELECTED CROSS-CLASSIFICATION SCHEMES

Two analyses of temporal stability are presented in this section. The first deals with individual rates within a given cross-classification model. As discussed previously, the t value and percent difference determine the statistical and planning significance associated with individual rate differences. Because planning uses for trip generation data usually involve geographical aggregations of travel estimates (traffic zone, development district, etc.), individual rate differences may cancel out. To measure the planning significance of aggregated differences on trip estimates, the 1960 and 1987–1988 calibrations of each model are applied to traffic zone (census tract) data taken from the 1980 census. Resulting aggregate differences are summarized at the zonal level [root mean squared (RMS) difference] and with regional totals. Temporally stable models are characterized by similar regional totals and small RMS differences at the zonal level. Also included in this analysis are three useful decomposition measures of the mean square difference proposed by Theil (*8*): (a) UM measures the fraction of mean square difference attributable to discrepancies in the means, (b) US refers to the fraction of this difference resulting from unequal standard deviations, and (c) UC estimates the corresponding fraction resulting from incomplete covariation (scatter).

Temporal stability does not necessarily imply accuracy in the resulting trip estimates. Because of the uneconomically large sample sizes required to estimate actual zonal trip totals, error calculations cannot be made at this level. Even regional trip totals are difficult to estimate from survey data because these totals are often sensitive to the specific methods used to factor the survey. The simple cross-classifications presented in Tables 3–5 probably do not produce sufficient accuracy at the zonal level for travel simulation purposes except, perhaps, for regional control totals of non-home-based trips. However,

TABLE 3 COMPARISON OF TRIP RATES STRATIFIED BY HOUSEHOLD SIZE

	Persons Per Household					
	1	2	3	4	5	6-9
			Total Trips Per Household			
1987-88 Survey	2.66	5.13	7.05	8.70	10.15	13.61
1960 Survey	1.26	3.41	5.19	6.58	7.26	7.79
Percent Diff.	111.11	50.44	35.84	32.22	39.81	74.71
"t" Statistic	14.86*	12.51*	7.79*	6.85*	5.47*	6.67*
			Home Based Work Trips Per Household			
1987-88 Survey	0.59	1.48	2.06	2.30	2.53	2.58
1960 Survey	0.54	1.53	2.16	2.28	2.28	2.44
Percent Diff.	9.26	-3.27	-4.63	0.88	10.96	5.74
"t" Statistic	1.06	0.89	1.07	0.26	1.55	0.56
			Home Based Non-work Trips Per Household			
1987-88 Survey	1.25	2.26	3.01	4.06	4.64	6.63
1960 Survey	0.53	1.37	2.08	2.85	3.25	3.33
Percent Diff.	135.85	64.96	44.71	42.46	42.77	99.10
"t" Statistic	12.22*	10.30*	6.06*	5.68*	3.89*	5.67*
			Home Based School Trips Per Household			
1987-88 Survey	0.07	0.12	0.34	0.69	1.50	2.08
1960 Survey	0.02	0.04	0.26	0.59	0.86	1.18
Percent Diff.	250.00	200.00	30.77	16.95	74.42	76.27
"t" Statistic	4.10*	6.78*	1.81	1.26	4.15*	3.01*
			Non-Home Based Trips Per Household			
1987-88 Survey	0.75	1.27	1.65	1.66	1.45	2.32
1960 Survey	0.17	0.46	0.70	0.86	0.86	0.84
Percent Diff.	341.18	176.09	135.71	93.02	68.60	176.19
"t" Statistic	15.02*	12.63*	8.77*	6.93*	3.22*	5.38*

* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 4 COMPARISON OF TRIP RATES STRATIFIED BY INCOME

	Household Income Code					
	0	1	2	3	4	5
			Total Trips Per Household			
1987-88 Survey	2.84	3.91	4.88	5.68	7.63	8.53
1960 Survey	1.54	3.76	5.54	6.87	8.06	9.15
Percent Diff.	84.42	3.99	-11.91	-17.32	-5.33	-6.78
"t" Statistic	5.70*	0.43	1.66	3.56*	1.46	1.23
			Home Based Work Trips Per Household			
1987-88 Survey	0.39	0.80	1.08	1.60	2.03	2.49
1960 Survey	0.52	1.59	2.07	2.48	2.76	2.77
Percent Diff.	-25.00	-49.69	-47.83	-35.48	-26.45	-10.11
"t" Statistic	1.34	6.28*	7.75*	8.04*	7.12*	1.80
			Home Based Non-work Trips Per Household			
1987-88 Survey	1.70	1.95	2.30	2.59	3.54	3.53
1960 Survey	0.78	1.53	2.35	2.86	3.39	3.97
Percent Diff.	117.95	27.45	-2.13	-9.44	4.42	-11.08
"t" Statistic	6.05*	1.83	0.18	1.21	0.72	1.33
			Home Based School Trips Per Household			
1987-88 Survey	0.22	0.30	0.33	0.39	0.57	0.43
1960 Survey	0.10	0.26	0.46	0.60	0.67	0.91
Percent Diff.	120.00	15.38	-28.26	-35.00	-14.93	-52.75
"t" Statistic	2.08*	0.43	1.20	2.22*	1.39	3.41*
			Non-Home Based Trips Per Household			
1987-88 Survey	0.53	0.87	1.17	1.10	1.49	2.08
1960 Survey	0.14	0.38	0.66	0.94	1.24	1.50
Percent Diff.	278.57	128.95	77.27	17.02	20.16	38.67
"t" Statistic	6.17*	4.29*	3.34*	1.18	2.15*	3.06*

INCOME CODES 0: Under $10,000 1: $10,000 - $14,999 2: $15,000 - $19,999 3: $20,000 - $29,999 4: $30,000 - $49,999 5: $50,000 - $69,999

N:Indicates insufficient data (less than 25 observations).

* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 5 COMPARISON OF TRIP RATES STRATIFIED BY AUTOMOBILE OWNERSHIP

	Cars Per Household					
	0	1	2	3	4	5-9
			Total Trips Per Household			
1987-88 Survey	2.18	4.56	7.74	9.57	8.81	13.38[N]
1960 Survey	1.79	5.41	8.32	9.95	11.53	17.78[N]
Percent Diff.	21.79	-15.71	-6.97	-3.82	-23.59	-24.75
"t" Statistic	2.45*	4.57*	2.45*	0.76	2.96	1.35
			Home Based Work Trips Per Household			
1987-88 Survey	0.72	1.10	2.00	2.70	3.56	5.08[N]
1960 Survey	1.03	1.97	2.61	3.64	4.29	5.33[N]
Percent Diff.	-30.10	-44.16	-23.37	-25.82	-17.02	-4.69
"t" Statistic	3.17*	13.90*	8.41*	5.40*	1.29	0.20
			Home Based Non-work Trips Per Household			
1987-88 Survey	0.98	2.15	3.49	4.16	3.37	5.69[N]
1960 Survey	0.55	2.34	3.65	4.09	4.64	9.11[N]
Percent Diff.	78.18	-8.12	-4.38	1.71	-27.37	-37.54
"t" Statistic	4.66*	1.57	1.00	0.21	1.45	1.20
			Home Based School Trips Per Household			
1987-88 Survey	0.16	0.25	0.55	0.69	0.78	0.23[N]
1960 Survey	0.12	0.42	0.79	0.81	0.89	1.33[N]
Percent Diff.	33.33	-40.48	-30.38	-14.81	-12.36	-82.71
"t" Statistic	0.89	3.44*	3.60*	0.86	0.26	1.71
			Non-Home Based Trips Per Household			
1987-88 Survey	0.32	1.07	1.69	2.01	1.11	2.38[N]
1960 Survey	0.09	0.68	1.26	1.41	1.71	2.00[N]
Percent Diff.	255.56	57.35	34.13	42.55	-35.09	19.00
"t" Statistic	6.38*	5.71*	4.14*	3.26*	1.22	0.37

N:Indicates insufficient data (less than 25 observations).
* Indicates statistically significant difference between the two means at significance level 0.05.

the formulations selected for inclusion in subsequent sections have been used successfully in regional travel simulation models.

Simple Two-Dimensional Cross-Classification Models

Compared with stratification by trip purpose only (Table 1), the cross-classification by household size and trip purpose presented in Table 3 significantly increases the differences between trip rates in the 1960 and 1987–1988 surveys for all trip purposes except home-based work. For work trips, the decline in household size and the increase in labor force participation rates have compensated over time. All other trip rate comparisons show large differences with high levels of statistical and planning significance (from 32 to 111 percent increase in total travel). Even home-based school trips (excluding district-sponsored school bus trips), which were constant in aggregate, show large increases when stratified by family size.

Table 4 shows that an income-based cross-classification scheme produces dramatically different patterns of temporal stability. No longer do all nonwork trip purposes show large increases in trip rates. Generally, home-based nonwork and school trip rates for households with incomes below $15,000 increase and households with incomes greater than this level now make fewer trips. Work trips have significantly declined, and non-home-based trips have increased for all income categories with valid sample sizes. With the exception of households with incomes below $10,000, total trip rates per household are relatively stable over time. (As noted previously, the household incomes recorded in the 1960 survey were converted to 1988 constant dollars before computing the rates in Table 4.)

A similar pattern is shown for automobile ownership in Table 5. Except for home-based work travel, zero-car households now show much higher trip rates than those recorded in 1960, with a compensating decline in trip rates for all car-owning categories. The percent reductions in trip rates tend to increase with automobile ownership, perhaps indicating diminishing returns in automobile ownership brought about by increasing saturation of the demand for automobiles and smaller household sizes. As in the income stratification, work trip rates generally decline and non-home-based trips significantly increase over time.

These temporal shifts are similar in pattern to those reported by Kollo and Purvis (*5*) for the San Francisco Bay Area between 1965 and 1981, except that their data showed smaller declines in work trips per household over time. However, their finding of a constant total household trip rate regardless of stratification variable can be misleading. This result was based on trip rates calculated from factored survey data, but the distribution of socioeconomic household characteristics has changed greatly over time. Table 6 illustrates this change by calculating trip generation with 1960 and 1987–1988 rates by census tract (about 970 zones within the Penn Jersey cordon line) using the appropriate socioeconomic data taken from the 1980 census.

Table 6 shows that the variable used in cross-classification has enormous impact on both the total number of trips gen-

TABLE 6 DIFFERENCE BETWEEN 1980 ZONAL TRIP GENERATION ESTIMATES ON THE BASIS OF 1960 AND 1987–1988 HOUSEHOLD RATES

Trip Purposes	Region Trip Total (10^6)		% RMS	Theil Statistics		
	1960 Rates	1987-8 Rates	DIFF.	UM	US	UC
Household Size Stratification						
Home Based Work	2.3	2.3	1.20	0.41	0.19	0.58
Home Based Non Work	2.5	4.1	45.72	0.69	0.30	0.01
Home Based School	0.4	0.7	45.50	0.67	0.33	0.00
Non-Home Based	0.8	1.9	71.36	0.69	0.30	0.01
TOTAL	6.1	9.2	39.51	0.69	0.30	0.01
Income Stratification						
Home Based Work	2.8	2.1	45.86	0.66	0.28	0.06
Home Based Non Work	3.5	3.9	13.03	0.60	0.15	0.25
Home Based School	0.7	0.6	25.93	0.56	0.31	0.13
Non-Home Based	1.2	1.7	39.07	0.72	0.25	0.03
TOTAL	8.2	8.3	5.83	0.04	0.01	0.95
Auto Ownership Stratification						
Home Based Work	3.0	2.1	55.64	0.69	0.30	0.01
Home Based Non Work	3.6	3.5	6.56	0.09	0.21	0.70
Home Based School	0.7	0.5	50.02	0.64	0.34	0.02
Non-Home Based	1.1	1.6	38.40	0.70	0.28	0.03
TOTAL	8.4	7.7	11.59	0.61	0.34	0.04

erated and the amount of forecast difference at the census tract level. Household size leads to a one-third underestimate of total trips and an almost 40 percent RMS difference at the tract level if 1960 rates are used to predict current travel. On the contrary, income (1980 census income categories were converted to 1988 dollars) produces only about a 1 percent overestimate of regional trips with just under 6 percent tract level RMS difference and automobile ownership produces an 8 percent underestimate with a 12 percent RMS difference.

By purpose, household size is the most stable variable for home-based work trips (1.2 percent RMS difference), automobile ownership for home-based nonwork (6.6 percent) and non-home-based travel (38.4 percent), and income for school travel (25.9 percent). The best models for home-based work and nonwork travel have temporal stabilities within the 10 percent planning limits, but school and non-home-based travel have large underestimates with 1960 rates, regardless of the stratification variable used.

In the Theil (*8*) tests, UM is the principal component of zonal trip differences between the 1960 and 1987–1988 rates for all models in Table 6 for which the percent RMS difference is large. Rate differences tend to average out for home-based nonwork travel with an automobile ownership stratification and for total travel when stratified by income, although significant differences in the standard deviations (US) still exist in the former case. Despite the small percentage RMS difference for work trips when stratified by household size, over 40 percent of the mean squared difference is attributable to differences in the mean and standard deviation, because of an almost perfect collinearity between the two sets of zonal trip estimates.

Impact of the Penn Jersey Cordon Line on Temporal Stability

Changes in the relationship of regional development patterns to the cordon line also influence the temporal stability of internal trip generation rates. As a result of the decentralization of population and employment that has occurred between 1960 and 1987, almost all of the rural land inside of the Penn Jersey cordon is now developed and large amounts of both residential and commercial development now exist outside of this cordon line (see Figure 1). This change significantly reduces internal work trip generation rates because many workers now cross the Penn Jersey cordon on the way to their place of employment.

Table 7 presents the impact of the Penn Jersey cordon on 1987–1988 work trips per employed resident. Current work trip rates increase significantly when the cordon line is extended to the nine-county boundary and even further when the cordon is eliminated entirely. As expected, the difference in current work trip rates is largest for rural areas near the cordon and smallest in Philadelphia's central business district. This, in part, explains the large reduction in 1987–1988 work trip rates compared with 1960 rates, as recorded in Tables 4 and 5. Home-based work trips display this tendency because of relatively long trip lengths. On the basis of the nine-county cordon, home-based work trips per employed resident have declined significantly since 1960, by about 14 percent overall.

Home-based nonwork trip lengths are much shorter and therefore are less influenced by the location of the cordon line. Table 8 shows that only small increases in trip rates occur when the cordon is extended to the entire region. As ex-

TABLE 7 STABILITY OF INTERNAL HOME-BASED WORK TRIP RATES PER EMPLOYED RESIDENT

	Area Type			
	CBD	Urban	Suburban	Rural
	1987-88 Rates for the Penn Jersey Cordon Line			
1987-88 Survey	0.65	1.27	1.27	1.02
1960 Survey	0.96	1.51	1.63	1.55
Percent Diff.	-32.29	-15.89	-22.09	-34.19
"t" Statistic	1.34	4.84*	9.93*	4.53*
	1987-88 Rates for the DVRPC Cordon Line			
1987-88 Survey	0.65	1.33	1.39	1.30
1960 Survey	0.96	1.51	1.63	1.55
Percent Diff.	-32.29	-11.92	-14.72	-16.13
"t" Statistic	1.34	3.65*	7.17*	4.58*
	1987-88 Rates Including All External Work Trips			
1987-88 Survey	0.72	1.38	1.46	1.44
1960 Survey	0.96	1.51	1.63	1.55
Percent Diff.	-25.00	-8.61	-10.43	-7.10
"t" Statistic	1.02	2.74*	4.98*	2.06*

* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 8 COMPARISON OF 1987–1988 HOME-BASED NONWORK HOUSEHOLD TRIP RATES BETWEEN DVRPC AND PENN JERSEY STUDY REGIONS

	Area Type			
	CBD	Urban	Suburban	Rural
DVRPC Region	1.00	2.12	3.40	3.65
Penn Jersey Region	0.96	2.03	3.18	3.44
Percent Diff.	4.17	4.43	6.92	6.10
"t" Statistic	0.09	0.57	1.55	0.51

	Cars Per Household					
	0	1	2	3	4	5-9
DVRPC Region	1.01	2.31	3.74	4.43	3.98	5.17
Penn Jersey Region	0.98	2.15	3.49	4.16	3.37	5.69
Percent Diff.	3.06	7.44	7.16	6.49	18.10	-9.14
"t" Statistic	0.17	1.23	1.38	0.74	0.75	0.37

* Indicates statistically significant difference between the two means at significance level 0.05.

pected, this increase is greatest for rural areas, but none of these differences are of planning or statistical significance. The location of the cordon line also has little effect on home-based nonwork trips when rates are stratified by automobile ownership.

Temporal Stability of Selected Multidimensional Cross-Classification Schemes for Home-Based Nonwork Travel

Travel simulations often model home-based nonwork travel with multidimensional cross-classification schemes that use combinations of trip purpose, family size, automobile ownership or income, and area type. Automobile ownership and income are rarely used together because of the high degree of collinearity between these variables. In this section, detailed trip rate tables stratified by income are omitted. Comparisons are limited to automobile ownership because fewer variable ranges are needed and because this variable is somewhat more temporally stable than income for home-based nonwork travel. Income displays much the same patterns of stability as automobile ownership. Income-based difference statistics are included in the summary tables, however.

Because of the relatively large number of cells in multidimensional cross-classifications, the entire 1987–1988 survey was used for comparison with 1960 data to improve the statistical significance of the results. Due to the relatively short average trip length, home-based nonwork trip rates do not differ greatly between the Penn Jersey and nine-county cordon areas (see Table 8).

Table 9 shows the stability of home-based nonwork trip generation rates cross-classified by automobile ownership and

TABLE 9 COMPARISON OF HOME-BASED NONWORK HOUSEHOLD TRIP RATES STRATIFIED BY AUTOMOBILE OWNERSHIP AND HOUSEHOLD SIZE

	Cars Per Household			
	0	1	2	3+
	One-Person Households			
1987-88 Survey	0.74	1.50	1.17[N]	1.40[N]
1960 Survey	0.34	1.03	1.19[N]	N
Percent Diff.	117.65	45.63	-1.68	N
"t" Statistic	5.14*	5.34*	0.05	N
	Two-Person Households			
1987-88 Survey	0.84	2.45	2.63	2.60
1960 Survey	0.50	1.71	2.19	2.48
Percent Diff.	68.00	43.27	20.09	4.84
"t" Statistic	2.26*	5.50*	3.21*	0.25
	Three-Person Households			
1987-88 Survey	0.75[N]	2.76	3.50	4.13
1960 Survey	0.72	2.15	2.91	3.08
Percent Diff.	4.17	28.37	20.27	34.09
"t" Statistic	0.06	2.20*	2.70*	3.10*
	Four-Person Households			
1987-88 Survey	2.13[N]	2.99[N]	4.60	4.64
1960 Survey	0.80	2.79	3.93	3.72
Percent Diff.	166.25	7.17	17.05	24.73
"t" Statistic	2.29*	0.46	2.52*	2.04*
	Five or More Person Households			
1987-88 Survey	3.19[N]	5.44[N]	6.22[N]	5.78
1960 Survey	0.86	3.18	4.70	5.11
Percent Diff.	270.93	71.07	32.34	13.11
"t" Statistic	4.94*	3.50*	3.61*	1.13

N: Indicates insufficient data (less than 25 observations).
* Indicates statistically significant difference between the two means at significance level 0.05.

household size. It might be argued that the temporal instability in household size rates shown in Table 3 resulted in part from not considering automobile ownership as well. Although somewhat more stable than the results with household size alone, the results in Table 9 still show a significant increase in trip rates calculated from the 1987–1988 survey data. Excluding cells with insufficient data, these rate increases range from about 13 percent to well over 100 percent. Cross-classification by automobile ownership does not eliminate the tendency of household size stratifications to be temporally unstable.

It is possible that cross-classification by area type as well might improve the stability of household size strata. This method would take into account the massive decentralization that has occurred since 1960. Households located in low-density areas of the region probably make more intensive use of their automobiles than do their urban counterparts. However, this three-way matrix contains far too many cells to be adequately estimated by the 2,424 responses from the 1987–1988 survey. Cross-classification by household size and area type alone does not improve the temporal stability of trip generation rates.

Because of decentralization, cross-classification by area type as well as by automobile ownership might be expected to improve temporal stability. In addition, accurate estimation of zonal home-based nonwork trip ends in cross-section (for a given year) often requires stratification by both automobile ownership and area type. Table 10 shows that this structure produced a relatively stable set of rates except for zero-car households, which have experienced a large increase in trip making in urban, suburban, and possibly rural areas (27 to 88 percent). Only four of these rates show significant statistical differences. Trip rate differences for car-owning households are almost always near or below the 10 percent limit for planning significance.

Table 11 presents the impact of these trip rate changes on census tract level home-based nonwork trip generation results on the basis of the 1980 census. Household size continues to be unstable, whether cross-classified by income or automobile ownership. Both models that include this variable have large RMS differences (30 and 34 percent) with significant UM and US components. Automobile ownership is somewhat more temporally stable than income. However, the introduction of area type as well produces slightly less stable rates for both variables, compared with simple stratifications (see Tables 4 and 5). Because of reductions in the trip rate standard deviations, there appears to be a small trade-off between accuracy in cross-section and temporal stability when area type stratifications are introduced. Automobile ownership continues to show temporal stability in regional totals for home-based nonwork travel.

However, the tendency of larger automobile ownership categories to have negative trip rate differences, seen in Table 5, largely disappears when area type strata are introduced. This change may result in part from the inclusion of the automobile-dependent portion of the nine-county region beyond the Penn Jersey cordon into the calculation of the 1987–1988 trip rates. When stratified by area type, there is little

TABLE 10 COMPARISON OF HOME-BASED NONWORK HOUSEHOLD TRIP RATES STRATIFIED BY AUTOMOBILE OWNERSHIP AND AREA TYPE

	Cars Per Household			
	0	1	2	3+
		Central Business District		
1987-88 Survey	0.40[N]	1.88[N]	2.00[N]	N
1960 Survey	0.41	1.29	1.76	2.00[N]
Percent Diff.	-2.44	45.74	13.64	N
"t" Statistic	0.03	0.78	0.14	N
		Urban		
1987-88 Survey	1.00	1.91	3.24	3.03
1960 Survey	0.53	1.73	2.64[N]	3.43
Percent Diff.	88.68	10.40	22.73	-11.66
"t" Statistic	4.23*	1.06	2.07*	0.64
		Suburban		
1987-88 Survey	1.19	2.47	3.83	4.63
1960 Survey	0.65	2.79	3.95	4.48
Percent Diff.	83.08	-11.47	-3.04	3.35
"t" Statistic	3.00*	1.99*	0.67	0.46
		Rural		
1987-88 Survey	0.78[N]	2.73	3.81	4.43[N]
1960 Survey	0.61	2.83	3.79	3.83
Percent Diff.	27.87	-3.53	0.53	15.67
"t" Statistic	0.34	0.29	0.06	1.13

N: Indicates insufficient data (less than 25 observations).
* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 11 DIFFERENCE BETWEEN HOME-BASED NONWORK HOUSEHOLD ZONAL TRIP GENERATION ESTIMATES FOR SELECTED TWO-DIMENSIONAL STRATIFICATIONS

Stratification Scheme	Region Trip Total (10^6)		% RMS	Theil Statistics		
	1960 Rates	1987-88 Rates	DIFF.	UM	US	UC
Auto Ownership by Household Size	3.0	4.0	30.20	0.68	0.26	0.06
Income by Household Size	3.1	4.4	34.10	0.70	0.25	0.04
Auto Ownership by Area Type	3.4	3.6	12.18	0.15	0.02	0.83
Income by Area Type	3.3	3.9	21.80	0.48	0.05	0.47

consistent evidence of the decline in automobile trip rates that is implied from the factor analyses of Kitamura and Kostyniuk (6) and others. The rapid development of rural areas on the fringe of the region significantly increases the automobile-related travel needs of households relocating from denser, less automobile-dependent areas. In addition, the high insurance and other operating costs associated with automobile ownership may tend to discourage households from keeping underused vehicles.

Temporal Stability of Total Travel Estimates from Composite Models

Most operational trip generation models are composites in the sense that different combinations of stratification variables are used for each trip purpose. This procedure allows differences in individual trip purpose models to cancel out in ways other than those shown in Tables 3, 4, and 5. Table 12 summarizes the differences in zonal total trip estimates from stylized composite models on the basis of income and automobile ownership. These differences resulted from the application of 1960 and 1987–1988 survey rates to 1980 census inputs. Home-based work rates (per employed resident) for the nine-county region were stratified by area type, home-based nonwork trip rates were cross-classified by area type and automobile ownership or income, and home-based school and non-home-based trips were stratified by automobile ownership or income. The automobile ownership composite model is similar to DVRPC's trip generation model (developed in the early 1970s during the resimulation study), except that in this model

TABLE 12 TOTAL TRIP GENERATION ESTIMATES FROM COMPOSITE MODELS

Model	Region Trip Total (10^6)		% RMS	Theil Statistics		
	1960 Rates	1987-88 Rates	DIFF.	UM	US	UC
Auto Ownership	7.6	7.8	6.98	0.08	0.03	0.89
Income	7.6	8.3	12.70	0.45	0.04	0.51

school travel is included with home-based nonwork travel and non-home-based trips are generated as zonal origins on the basis of employment and the number of occupied dwelling units. Because neither end of these trips is at the home, household variables cannot be applied except perhaps to produce non-home-based regional control totals.

Overall, the automobile ownership model showed good stability with only 3 percent difference in the regional total of trips and 7 percent RMS difference at the tract level, with most differences due to incomplete covariation. The income-based model was not quite as stable (9 percent difference at the regional level and 12.7 percent tract level RMS difference with a significant UM component) but was still reasonably good given that almost 30 years had passed between the surveys.

CONCLUSIONS

Clearly, the selection of variables used in the cross-classification scheme has great impact on the temporal stability of the resulting trip generation model in the Delaware Valley region:

- Internal to the Penn Jersey cordon area, home-based work trip rates were most stable when stratified by household size, as a result of compensating changes in household size and labor force participation rates and increases in the percentage of internal-external trips over time.
- The location of the cordon line has a significant impact on internal work trip rates because of a relatively long trip length and the large amount of residential and commercial development now located near or outside of the Penn Jersey cordon.
- When viewed from the perspective of work trips per employed resident, home-based work trips within the nine-county region have declined by about 14 percent, on average, since 1960.
- Household home-based nonwork trip rates stratified by household size were temporally unstable even when cross-classified by income, automobile ownership, or area type. A three-way cross-classification by household size, automobile ownership (or income), and area type may improve stability, but the sample size of the 1987–1988 survey was too small to estimate this model.
- Automobile ownership appears somewhat more temporally stable for home-based nonwork trip rates than income, although these variables have similar patterns of stability because of covariation.
- A home-based nonwork model, cross-classified by automobile ownership and area type, displayed reasonably good stability except for zero-car households, for which trip rates have increased significantly over time.
- Household non-home-based trip rates have increased significantly regardless of the variables used in cross-classification.
- A realistic composite trip generation model using appropriate combinations of automobile ownership and area type strata for each trip purpose displayed excellent temporal stability in the Delaware Valley region, with less than 7 percent RMS difference between zonal total trip estimates on the basis of the 1960 and 1987–1988 rates.

This apparent temporal stability in part results from compensating changes in individual rates and therefore does not guarantee accurate long-range forecasts, particularly when significant travel determinants, omitted from the model, change over time. In addition, errors in the forecasts of the socioeconomic trip generation inputs significantly influence the accuracy of trip forecasts. However, appropriately specified disaggregate trip generation models may be sufficiently stable to be valuable tools for testing long-range transportation plans.

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