CONCLUSIONS

The experience with the synthetic four-purpose trip generation and distribution model in small communities in western Canada has been good. It suits the needs and constraints of the communities and provides an appropriate level of accuracy at a reasonable cost. The model's sensitivity analysis helps to speed up the calibration and may increase the planner's confidence in the validity of the process and its results. There is sometimes a need, however, to carry out a full transportation analysis of a selected community in order to verify the basic data that can be used in other communities.

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Transferability of Trip Generation Models

Lawrence C. Caldwell III and Michael J. Demetsky

Cross-classification, disaggregate regression, and aggregate regression trip generation models and trip rates were developed for three cities. The model for each of the cities was transferred to the two other cities and comparisons were made. The comparisons revealed that models calibrated on aggregate zonal data perform better than models calibrated with disaggregate household data when aggregate data are used for forecasting. However, if cross-classification models are acceptable, they can be transferred between cities if good judgment is used to select cities that are similar enough for this purpose. Recommended is the establishment of a standard procedure for data collection and trip generation analysis in selected studies of the near future so that the transferability question can be properly addressed. The emphasis should be on the development of new prototype models for application in groups of cities.

Trip generation is that phase of the urban transportation planning process that establishes relations between urban activity and travel. In the past, each transportation study has calibrated its own set of trip generation procedures based on origin-destination (O-D) data from home interview surveys. Data collection through O-D surveys is costly, especially in small cities where a high sample rate is required. Accordingly, the Federal Highway Administration (FHWA) has advocated planning methods that reduce data collection requirements (1). In this regard, the goal of FHWA is to develop a travel simulation procedure that is based on using information and experience from one locality to develop trip generation and trip distribution models that can be applied in other areas.

There is little documented experience concerning the application of the synthetic trip generation analysis procedures advanced by FHWA. Therefore, there was a need to test the transferability of these trip generation models and the adequacy of the prescribed method. Also, there was a need to determine the suitability of the use of the FHWA method for transportation planning in Virginia. This determination included calibrating and transferring models and the availability of forecasting data.

TECHNICAL ISSUES

Before the trip generation methodology is explicitly considered, certain technical issues that influence the performance of the modeling procedures being examined, but currently unresolved, are identified. The specific considerations addressed are area classification strategies, local versus synthetic models, and aggregate versus disaggregate data.

Area Classification

Applied methods of classifying cities for the purpose of aiding transportation planners in transferring trip generation models between cities were examined. One approach classifies cities by population and automobile availability (2). Automobile availability was found to be highly correlated with trips per person; however, areas that have high automobile ownership rates generated fewer trips per person than areas that have low automobile ownership rates (3). Consequently, the validity of this classification scheme is questionable because one would expect greater automobile availability to lead to a greater number of trips.

Another method of classifying cities is based on their structure (4). This technique measures city structure by the time distribution of job opportunities within the metropolitan area. This classification method appears to be more applicable to trip distribution than to trip generation because it is potentially useful for classifying cities in order to transfer gravity-model friction factors.

A third method classifies cities according to their dominant economic activity (5-9). This classification scheme is based on the percentage of the labor force employed in various industries and is a good measure of the distribution of total land use in the city. Since trip attraction rates generally depend on land use type, this classification method is sensitive to the trip attraction intensity and distribution in the area.

A fourth method of classifying cities (10, 11) uses factor and cluster analyses to group cities according to selected characteristics (variables) input to the factor analysis. The factor analysis groups similar single measures (individual variables) into factors and rates each city according to the set of generated factors. The cluster analysis then involves forming groups such that the within-group variances are minimized while the between-group variances are maximized. Factor analysis appears to be the most comprehensive method; however, it is complicated and the inclusion of extraneous variables may confound the results of the classification scheme.

None of the methods described for classifying cities has been applied for the specific purpose of identifying urban characteristics that associate directly with differences in trip generation activity. Consequently, no method is available for making a strong case for transferring models between selected pairs of cities.

In-depth testing of the city classification-model transferability issue was limited in the study because of (a) the incompatibility between the models developed here with Virginia data and those given in the FHWA report and (b) the limited number of cities for which models were collected. The problem of model transferability can be properly addressed only when a large number of models that are based on the same parameters are available from a wide range of cities.

Local Versus Synthetic Models

A number of problems are encountered in the transfer of transportation forecasting models. For instance, in order to test the validity of a transferred trip generation model, the productions and attractions must be processed through the trip distribution, mode choice, and traffic assignment phases to show link volumes that are comparable with traffic count data. This procedure must be employed with caution because of the multiple sources of potential error that affect the projected volumes. In addition to the possibility of erroneous estimates of trip ends, the flows that result from borrowed parameters for the trip distribution model or the route assignment role that is employed may be wrong. Thus, if the simulated flows do not agree with the observed values, the exact source of error is nearly impossible to specify.

Another possible problem in borrowing models is that the variables used in the borrowed model must be available locally and must be easily forecast. For example, a large number of cross-classification models use automobile ownership and income as the independent variables, but these models were difficult to use in Virginia because income information was not directly available.

Aggregate Versus Disaggregate

Another technical consideration in this study concerns the application of a disaggregate model to aggregated data. Cross-classification curves are calibrated on disaggregate household data, but generally aggregated zonal averages are used for forecasting. Much of the variance in data that can be accounted for in the disaggregate model is lost when data are aggregated to the zonal level. When zonal averages are used with the cross-classification model, one must assume that the number of trips produced by the average household in a zone is equal to the average number of trips produced by the households in the zone. This assumption was found to be false. For example, in Roanoke the average household size was 3.23 persons and the trip rate that corresponds to this household size was 8.21 trips/household; however, the average number of trips per household was only 7.60, which resulted in 8 percent overestimates of the total trip productions. When a disaggregate model is used with aggregated data, some measure of the distribution (e.g., standard error) should be given so that the magnitude of this estimation error can be determined.

TRIP PRODUCTION MODELS

In order to test the transferability of cross-classification procedures, models were developed for selected cities in Virginia. These cities were chosen on the basis of certain similarities and on the availability of data. Two pairs of cities were selected for study. These cities along with the selected characteristics are listed in Table 1. Originally Lynchburg and Roanoke were selected as pair 1, but the necessary data were not available for Lynchburg. Therefore, the study concentrated on Roanoke, Harrisonburg, and Winchester.

The two explanatory variables were selected to be automobile ownership and household size. Although income is highly recommended by FHWA as one of the independent variables, it was not used in this study because information on incomes is not available in Virginia. These cross-classification trip generation models are exemplified by the curves developed for Roanoke as shown by Figures 1-3.

Regression equations were also calibrated with the household data from the O-D survey. These equations used household size and automobile ownership as the independent variables so that they could be compared with the cross-classification trip rates. The household regression equations obtained are as follows:

In Harrisonburg,

$$\text{Trips/household} = -1.48 + 1.85 \times \text{household size} + 3.35 \times \text{automobiles/household} \quad (1)$$

Table 1. Characteristics of selected cities.

City	Population in 1970	Persons per Household	Automobiles per Household	Per Capita Income ($)
Lynchburg	70 842[a]	3.02	1.140	2906
Roanoke	156 621[a]	2.97	1.224	3085
Harrisonburg	14 605	2.79	1.120	2742
Winchester	14 643	2.80	1.090	2954

[a] Urbanized area population.

Figure 1. Roanoke percent households by automobile ownership and household size.

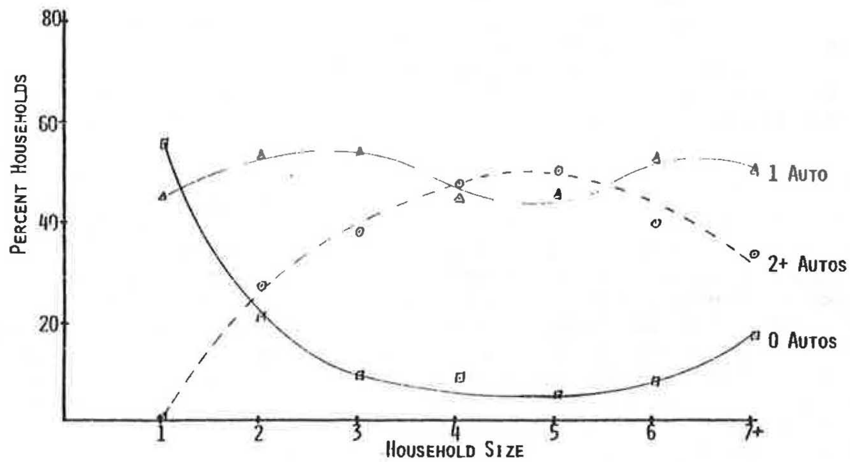

Figure 2. Roanoke trip rates by automobile ownership and household size.

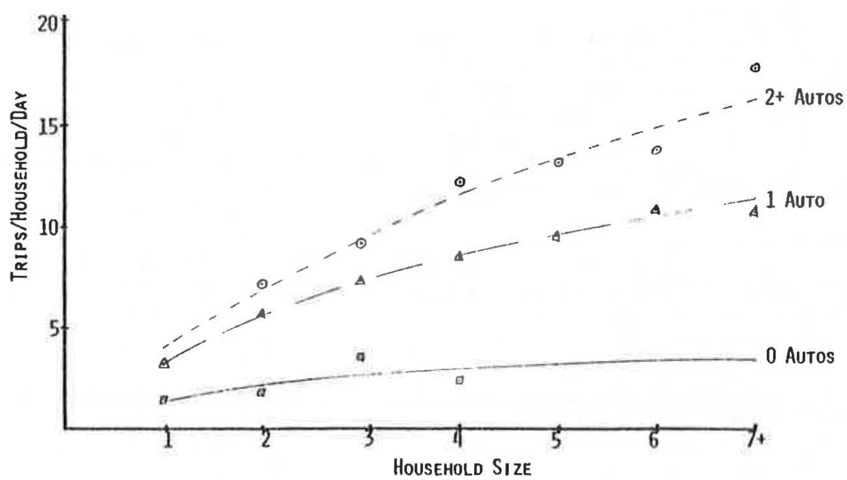

Figure 3. Roanoke percent of trips by trip purpose and household size.

Table 2. Calibrated model predictions.

City	Trips Reported	Trips Predicted: Cross-Classification Total	Cross-Classification χ^2	Disaggregate Regression Total	Disaggregate Regression χ^2	df	χ^2 Required for Significance at $\alpha = 0.05$
Disaggregate data							
Roanoke	17 340	17 332	1171	17 333	1359	160	190
Winchester	11 298	11 295	405	11 298	460	50	67
Harrisonburg	9 174	9 117	599	9 346	819	96	119
Aggregate data							
Roanoke	17 340	18 658	3157	17 250	1333	160	190
Winchester	11 298	11 801	1004	11 274	453	50	67
Harrisonburg	9 174	9 091	1767	9 299	798	96	119

Table 3. Transferred model predictions by using disaggregate data.

City	Cross-Classification: Roanoke n	Roanoke χ^2	Winchester n	Winchester χ^2	Harrisonburg n	Harrisonburg χ^2	Disaggregate Regression: Roanoke n	Roanoke χ^2	Winchester n	Winchester χ^2	Harrisonburg n	Harrisonburg χ^2	df	χ^2 Required for Significance at $\alpha = 0.05$
Roanoke	17 332	-	18 260	91	19 554	368	17 333	-	18 399	70	19 706	336	160	190
Winchester	10 707	46	11 295	-	11 977	80	10 674	40	11 298	-	12 051	65	50	67
Harrisonburg	8 127	172	8 646	49	9 117	-	8 355	112	8 892	30	9 346	-	96	119

$R^2 = 0.6903$; standard error of estimate of the mean (SE) = 0.7709.

In Roanoke,

$$\text{Trips/household} = -0.28 + 1.27 \times \text{household size} + 3.06 \times \text{automobiles/household} \qquad (2)$$

$R^2 = 0.5076$; SE = 0.7947.

In Winchester,

$$\text{Trips/household} = -0.66 + 1.35 \times \text{household size} + 3.54 \times \text{automobiles/household} \qquad (3)$$

$R^2 = 0.5909$; SE = 0.7562.

In addition to the cross-classification matrices and disaggregate regression equations, regression equations were calibrated for Roanoke on aggregated data used in the Roanoke area transportation study of 1965. The available data for each traffic zone included number of total persons, number of occupied dwelling units, number of passenger cars, school attendance by zone of school (excluding college), and total blue-collar and white-collar employment by zone of work (TOTEMP).

The home-based work, home-based other, and non-home-based productions and attractions by traffic zone for the base year (1965) were available as vehicle trips. They were then converted to person trips by using automobile occupancy rates by trip purpose developed for Charlottesville. The total person trip productions computed by this expansion method compared very well with the total trips reported in the Roanoke area transportation study (353 493 as compared with 353 385).

The following regression equations were then calibrated for each of the three trip purposes:

Home-based work productions,

$$\text{HBW P} = 14.77 + 1.25 \times \text{automobiles} \qquad (4)$$

$R^2 = 0.88$; SE = 0.353.

Home-based other productions,

$$\text{HBO P} = -84.59 + 3.07 \times \text{automobiles} \qquad (5)$$

$R^2 = 0.89$; SE = 0.377.

Non-home-based productions,

$$\text{NHB P} = -5.75 + 1.25 \times \text{TOTEMP} + 1.09 \times \text{dwelling units} \qquad (6)$$

$R^2 = 0.90$; SE = 0.728.

Total production,

$$\text{Tot P} = -47.63 + 5.12 \times \text{TOTEMP} \qquad (7)$$

$R^2 = 0.93$; SE = 0.628.

MODEL EVALUATIONS

Trip productions were predicted by the cross-classification and regression models by using both household data (from the O-D survey) averaged for the traffic zones (aggregated data) and summing predictions for the individual household observations (disaggregate data) for each zone. In both cases, in all three study areas the distribution of predicted trips was statistically found to be significantly different from the reported trips. The total predictions and chi-square values are shown in Table 2. These results show that, even while using disaggregate data with the disaggregate models, the models do not perform accurately.

In addition to comparing actual trip productions reported in the O-D survey with trip productions predicted by using the calibrated models, the calibrated models were compared with models transferred from the other two study areas. The results of transferring the models are shown in Table 3. The Winchester cross-classification model transferred acceptably to both Roanoke and Harrisonburg and the Roanoke cross-classification model transferred adequately to Winchester. These results show that cross-classification models can be transferred between cities; however, care should be taken in selecting similar cities.

The cross-classification models were also evaluated with expanded base-year planning data aggregated to the zonal level. These results are shown in Table 4. The expectation that the disaggregate cross-classification models would not perform as well when aggregated data were used was found to be true, as can be seen in the higher chi-square values (compare Tables 3 and 4).

A comparison of the predictive ability of the cross-classification model versus the aggregate and disaggregate regression models for Roanoke is found in the table below. As can be seen from this table, the aggregate regression model predicts trip productions better at the traffic zone level (lowest chi-square value) and on the citywide level (best total productions).

Roanoke Productions	Productions	Chi-Square (compared with actual)
Actual	353 493	0
Cross classification	383 318	93 003
Aggregate regression	353 494	30 505
Disaggregate regression model	353 957	57 294

It is more difficult to forecast data at the household level than at the zonal level and the accuracy of forecast houshold data has to be determined before a direct comparison can be made. Overall, models calibrated on aggregated zonal data appear to perform better than models calibrated on disaggregate household data when used with forecast aggregated zonal data.

Table 4. Transferred cross-classification models by using aggregate data.

City	Model	Total Productions	χ^2
Roanoke[a]	Calibrated	383 318	
	Winchester	389 857	578
	Harrisonburg	436 390	9776
Winchester[b]	Calibrated	62 822	
	Roanoke	63 139	60
	Harrisonburg	68 619	672
Harrisonburg[c]	Calibrated	46 306	
	Roanoke	43 521	320
	Winchester	43 553	362

[a]df = 160; χ^2 required for significance at $\alpha = 0.05 = 190$.
[b]df = 50; χ^2 required for significance at $\alpha = 0.05 = 67$.
[c]df = 119; χ^2 required for significance at $\alpha = 0.05 = 119$.

Table 5. Roanoke trip attraction rates.

Trip	Trips per Household	Trips per Employee	Trips per $1000 Retail Sales	Trips per Student
Home-based work		1.471		
Home-based shopping			0.195	
Home-based school				[a]
Home-based other	1.046	1.321		
Nonhome based	0.331	0.412	0.126	

[a]No school enrollment data available.

Table 6. Land use trip rate calculations for Roanoke study zones.

Item	Trip Rate	Trip Ends
Traffic zone 1		
286 dwelling units	10.0 trips/dwelling unit	2 860
425 hotel rooms	11.3 trips/room	4 802
14 461 m^2 office space	125.78 trips/1000 m^2	1 819
7637 m^2 manufacturing space	44.12 trips/1000 m^2	337
3 gasoline stations	748 trips/station	2 244
Total		12 062
Traffic zone 67		
1083 dwelling units	10.0 trips/dwelling unit	10 830
1465 m^2 restaurant space	1768.94 trips/1000 m^2	2 591
2048 m^2 warehouse space	53.91 trips/1000 m^2	110
5401 m^2 office space	125.78 trips/1000 m^2	679
710 elementary students	0.51 trips/student	362
Total		14 572
Traffic zone 151		
19 080 m^2 shopping center	536.92 trips/1000 m^2	10 244

Note: 1 m^2 = 10.76 ft^2.

TRIP ATTRACTION ANALYSIS

For the analysis of trip attractions, three techniques were considered. The first was the standard method recommended by FHWA (1), which uses general trip rates. A second method used the linear regression method, and the third employed specific land use trip rates to predict trip ends.

Trip Rate Procedures

The method for predicting trip attractions suggested by FHWA (1) is described as "a simplified approach... based upon the development of trip rates with a matrix."

Trip attraction rates for the Virginia test cities were calculated from available planning data. In computing the rates, the numbers of trips produced for the types of trip purposes were summed for all traffic zones to give a citywide total of trip attractions by each purpose. Total trip attractions for each purpose were set equal to total trip productions because trip production prediction methods are generally considered to be more accurate than trip attraction prediction techniques. The values of the socioeconomic variables (total employment, retail sales, number of households, and number of students) were also summed for all traffic zones to get citywide totals. The trip attraction rates were then computed to provide the matrix of trip rates for Roanoke in Table 5.

Regression Procedures

Attraction regression equations developed for Roanoke are shown below with the index of determination (R^2). Calibrated regression equations for trip attractions are as follows:

Home-based work attractions,

$$\text{HBW A} = -9.72 + 1.19 \times \text{TOTEMP} \tag{8}$$

$R^2 = 0.97$

Home-based other attractions,

$$\text{HBO A} = 123.82 + 1.39 \times \text{TOTEMP} + 1.18 \times \text{automobiles} \tag{9}$$

$R^2 = 0.68$

Non-home-based attractions,

$$\text{NHB A} = -5.75 + 1.26 \times \text{TOTEMP} + 1.09 \times \text{dwelling units} \tag{10}$$

$R^2 = 0.90$

Total attractions,

$$\text{TOT A} = 196.22 + 3.81 \times \text{TOTEMP} + 2.47 \times \text{dwelling units} \tag{11}$$

$R^2 = 0.88$

Land Use Trip Rates

Another method of predicting trip attractions involves the use of rates based on specific land uses. Some of these rates have been published by the Institute of Transportation Engineers (ITE) and by the Arizona Department of Transportation (12-14). In this method the number of units in each land classification is multiplied by the trip rate for that particular land use and summed for the analysis area to predict trip ends (both productions and attractions).

Table 7. Comparison of actual productions and attractions with predictions by using cross-classification, regression, and land use trip rates.

Study Zone	Actual Productions and Attractions[a]	Land Use Trip Ends[b]	Error (%)	Cross-Classification Productions and Attractions[a]	Error (%)	Regression Productions and Attractions[a]	Error (%)
Roanoke							
TZ 1	10 414	12 062	15.8	17 587	68.9	15 918	52.8
TZ 67	14 397	14 572	1.2	15 405	7.0	15 003	4.2
TZ 151	8 519	10 244	20.2	1 718	-79.8	1 646	-80.7
Lynchburg							
TZ 11	4 165	4 489	7.8				
TZ 20	3 478	1 780	-48.8				
TZ 34	25 862	25 960	0.4				

[a]Data are from 1965. [b]Roanoke data are from 1966; Lynchburg data are from 1968.

Available rates for Virginia were compared with the rates published by Arizona and ITE to determine which rates to use in this study. The rates from all three studies appeared to be very similar, with the exception of the rates for small shopping centers.

The trip rates published by ITE were used in this study because the land use classifications were slightly easier to use than those from the Arizona study. This method of estimating trip ends was performed on three traffic zones in Roanoke and on three zones in Lynchburg. We assumed that Lynchburg would be included in the study at the time this analysis was performed. A large number of units could not be classified from the aerial photograph alone, but when a city directory was used in conjunction with the aerial photograph, all units could be classified. Thus, the need for an on-site study was eliminated. An example of the land use characteristics and trip end calculations for traffic zones is shown in Table 6 (12). The floor areas were measured on the area photographs by using the scale of the photograph, the dimensions of the building, and the number of floors. This procedure is rather tedious and approximately 32 person-h were required to classify the six traffic zones.

Evaluation of Procedures

It is not necessary to transfer standard trip rates from one city to another because the trip rates can be computed from the planning data available for each city. The trip rates are based on total predicted trip productions so that total productions and attractions will balance. If trip rates were transferred from another city, the production totals and attraction totals would disagree. By using rates calculated from total productions and the city's own planning data, this problem is avoided. Because the rates are based on total trip productions, separate rates have to be computed for each trip production model transferred to the city. For example, if the Roanoke and Harrisonburg cross-classification models were transferred to Winchester, separate rates would have to be computed for each of the two transferred models because the total trip production varies with the transferred trip production model.

A comparison of the Roanoke actual attractions and estimated attractions was made by using the standard trip rate method for each traffic zone. Although the total attractions predicted by using the standard trip rates were 8.43 percent greater than the actual attractions, the zonal predictions were in error an average of 74.4 percent. The total attractions for Roanoke predicted by using the regression equations were 0.95 percent greater than the actual attractions; however, the zonal predictions were in error an average of 92.6 percent.

These results imply that the procedures for predicting trip attractions can be very inaccurate. Either revision in these methods or a new method of predicting trip attractions is needed. The use of specific land use trip rates is one such new method. The trip ends predicted by using the land use trip rates were compared with the actual productions and attractions for both Lynchburg and Roanoke. The Roanoke predictions were also compared with the regression and cross-classification predictions. These comparisons are shown in Table 7. The high percentage of error for traffic zone 20 of Lynchburg would indicate the possibility that the land use changed drastically between 1965 and 1968. Except for this zone, the land use trip rate method predicted trip ends reasonably well. It predicted much better than either the cross-classification or the regression method did in Roanoke. One disadvantage of the land use trip rate method is that it requires a directional factor to split trip ends to productions and attractions. A second disadvantage is that the method requires very specific land use forecasts.

CONCLUSIONS

An investigation of the application in Virginia of the trip generation procedures described by FHWA (1) revealed certain findings that can be interpreted to show how trip generation analysis procedures can be improved and standardized. Models calibrated on aggregate zonal data performed better than models calibrated on disaggregate household data when they were used with forecasts of aggregated data. The average rates given by a cross-classification table that are applied at a disaggregate level were not sensitive to locational (zonal) variations. It was also shown that cross-classification models can be transferred between cities; however, care should be taken in selecting similar cities between which the models are to be transferred.

The trip attraction forecasting methods based on areawide trip rates are not sensitive to specific site characteristics. Procedures for forecasting trip attractions that are based on land use trip rates appear to warrant consideration because of their sensitivity to specific land uses.

The reported findings led to certain recommendations for improving the synthetic trip generation analysis procedures. Initially, all states should be encouraged to use standard procedures for trip generation analysis and data collection for a period in the future so that information and results can be properly compared. The emphasis should be on the development of prototype models for application in groups of cities. A determination should be made of how accurately disaggregate household data can ultimately be forecast. If disaggregate data cannot be forecast accurately, then the study of disaggregate models is futile because they do not perform as well as aggregate models that use aggregate data.

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Abridgment

Analysis of Intercity Travel Markets in New York State

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This paper presents the results of an analysis of intercity travel market segments in New York State's Empire Corridor (New York City-Albany-Buffalo). The intercity travel data were obtained from a stratified random sample of Empire Corridor residents that was taken in the spring of 1979. The survey collected information on respondents' intercity travel habits and modal awareness, familiarity, and accessibility. Detailed analyses were performed on the Empire Corridor nonbusiness travel market. Tables were developed to show the demographic distributions and mean trip rates of nontravelers, light travelers (one to five trips per year), and heavy travelers (more than five trips per year). A multivariate statistical procedure, automatic interaction detector, was used to attempt to uncover the variables that best explain the variation in trip making. The results indicate that geographic stratum is the best travel segmentation variable. Other variables that have an important influence on intercity travel include age, household size, and knowledge of National Railroad Passenger Corporation (Amtrak) service (a measure of the information level of corridor residents). The variables collected in the survey had different effects on each geographic stratum, which supports the assumption that the intercity travel market is heterogeneous.

In response to the growing use of intercity public transportation in New York State, the New York State Department of Transportation performed a study to aid in the planning and marketing of intercity rail passenger service. A telephone survey of rail corridor (New York City, Albany, and Buffalo) residents was conducted in June 1979 to determine the characteristics of the intercity travel market in New York State.

Because different travel market segments are likely to vary in demand potential, intercity travelers were divided into appropriate markets for more detailed study. A literature search of market segmentation in intercity travel revealed few studies in the analysis of intercity travel market segments. Most of the research has been oriented toward intercity (or corridor) travel demand models, with travel segmentation by purpose and mode. Detailed market segmentation has been limited, for the most part, to intraurban travel [see, for example, Dobson and Tischer (1)]. This paper presents the results