AN EVALUATION OF THE TRANSFERABILITY OF CROSS CLASSIFICATION TRIP GENERATION MODELS

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

This report describes the results of the application in Virginia of the trip generation procedures described in the Federal Highway Administration report entitled Trip Generation Analysis and published in 1975. Cross classification models, disaggregate regression models, aggregate regression 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 forecasting with aggregate data. However, if cross classification models are acceptable, they can be transferred between cities if good judgement is used to select cities that are similar enough for transferring models. The report recommends 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.

1982

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1984

SUMMARY OF FINDINGS

An investigation of the application in Virginia of the trip generation procedures described in the Federal Highway Administration report entitled Trip Generation Analysis and published in August 1975 revealed the following general findings.

1. The data sets available for developing cross classification trip production models did not include income data. This omission prohibited the authors from developing models using the recommended set of variables, i.e., income and auto ownership, unless they chose to estimate income as a secondary variable from other available data. Since housing values, the typical surrogate for income, have been unstable due to rapid inflation, trip production models were calibrated using household size and auto ownership as the variables. Models using these variables had been developed elsewhere and have not been shown to be inferior to the income-auto ownership models.

2. An investigation of different methods that have been designed to classify cities revealed that, at this time, no particular method can be recommended to aid in establishing those cities between which travel demand models can be transferred.

3. The average rates given by a cross classification table that are applied at a disaggregate level are not sensitive to locational (zonal) variations.

4. Cross classification models can be transferred between cities; however, good judgement should be used in selecting similar cities between which the models are to be transferred.

5. Models calibrated on aggregate zonal data perform better than models calibrated on disaggregate household data for forecasts with aggregated data.

6. The trip attraction forecasting methods based on area-wide trip rates are not sensitive to specific site characteristics.

7. Procedures for forecasting trip attractions that are based on land use trip rates such as those provided by the Institute of Transportation Engineers and the Arizona Department of Highways appear to warrant consideration because of their potential sensitivity to specific land uses.

1986

RECOMMENDATIONS

The findings presented above led to the following recommendations.

1. That a preliminary classification scheme for grouping cities with similarities in travel behavior be developed. Hypotheses should be tested concerning the relationship between trip generation rates and city characteristics in order to establish empirically a basis for transferring models. Measures of population, land use development, and economic activity appear to be promising dimensions for explaining differences in the aggregate travel demands among urban areas.

2. That a standard procedure for trip generation analysis and data collection be used for a broad set of cities over a period of time 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. The data requirements and variables used should be explicitly considered.

3. That the Department develop new cross classification production models and trip rate attraction models for studies in the immediate future, with the objective of later transferring them to appropriate areas. The transferability of the models should be tested according to the procedures used in the present study.

1988

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INTRODUCTION

Trip generation is that phase of the Urban Transportation Planning Process (UTPP) in which relationships between urban activity and travel are established. A trip generation model provides a functional relationship between travel and the land use and socioeconomic characteristics of the units to (attractions) and from (productions) which travel is made. In the past each transportation study has usually 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, however, especially in small cities where a high sample rate is required. Accordingly, the Federal Highway Administration (FHWA) has been advocating planning methods which reduce data collection requirements.(1) In this regard, the goal of the 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.

Regarding trip generation, the FHWA approach involves transferring cross classification models for residential trip generation and land use trip rates for nonresidential trip generation. The two procedures are described as follows:(2)

1. Cross classification is a technique in which the change in one variable (trips) can be measured when the changes in two or more other variables (land use-socioeconomic) are accounted for. Cross classification is not heavily dependent upon assumed distributions of the underlying data, and, therefore, is sometimes referred to as a "nonparametric" or distribution free technique. Basically the technique stratifies "n" independent variables into two or more appropriate groups,

creating an n-dimensional matrix. Observations on the dependent variables are then allocated to the cells of the matrix, based on values of the several independent variables, and then averaged.

2. Non-residential trip generation is usually based upon an initial stratification of trip data by trip purpose and attraction variables considered most pertinent. For example, work trip rates may be based upon total employment, school trips on school enrollment and shop trips on retail sales. The rates should further be stratified by land use density or categories within an activity type (e.g., regional shopping center, CBD, or strip commercial). The rates developed are strictly ratios between trips and the variable chosen such as trips/employee or trips/student. The data used are usually aggregate data summarized to some multizonal system.

In recent years, the most common method used for trip generation analysis has been multiple linear regression.(3) Here equations are developed in which trips, or a trip rate, i.e., trips per household, is related to independent variables which explain the variations in the dependent variable. The equations are usually developed by trip purpose and generally are based on data aggregated at the zonal level as observations. Both productions and attractions have been estimated with regression models.

Another method for performing trip generations is to classify areas by their specific land use and to use, or "borrow", trip rates available in sources such as <u>Trip Generation</u> (1976),(4) which is published by the Institute of Traffic Engineers, and <u>Trip Generation Intensity Factors</u> (1976),(5) a revision of <u>Trip Generation by Land Use</u> (1974),(6) published by the Arizona Department of Transportation. This method involves predicting trip ends (origins plus destinations) instead of trip productions and attractions.

NEED FOR RESEARCH

There is little documented experience concerning the application of the synthetic trip generation analysis procedures advanced by the 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.

OBJECTIVES

The purpose of this research was to test the transferability and application of the synthetic FHWA trip generation methodology as documented in August 1975. The original study objectives were to —

1. determine a basis for transferring travel models between areas;

2. make direct comparisons between trip ends predicted from models calibrated with local data and models selected from other areas; and

3. determine relationships between observed traffic volumes and those that are simulated by trip generation, trip distribution and traffic assignment models.

The above project objectives were subsequently restated with minor modifications because of the following reasons:

1. The data available for selected cities in Virginia did not include the income variable and hence did not permit direct comparisons among models calculated for cities in Virginia and the models provided in the August 1975 report. This situation severely restricted the ability to achieve the first objective as stated in the Working Plan. This objective was reduced in scope to objective 1 in the final statement of objectives.

2. The major emphasis of this project was on the second objective as stated in the Working Plan. For the purposes of the actual study, this objective was expanded into three objectives (objectives 2, 3, and 4 as stated below).

3. Objective 5 in the final report is an attempt to draw experience on model transferability from the study findings.

4. The original objective under 3 was not addressed because of the extensive time that would have been required to develop the proper data. This objective was also superfluous to the primary purpose of the study.

Accordingly, the objectives addressed in this study were to —

1. test the transferability property by developing and comparing models from different cities in Virginia;

2. compare the predictive ability of cross classification models with that of regression models calculated from a similar data base;

3. test the application of land use trip rates in estimating trip ends (combined productions and attractions);

4. evaluate the appropriateness of a general trip attraction rate table for urban areas in Virginia; and

5. explain differences in observed trip attractions and productions among different cities.

TECHNICAL ISSUES

Before the methodology is considered, certain technical issues which influence the performance of the modeling procedures studied, but which are currently unresolved, are briefly considered. The purpose of this section is, therefore, to show the reader where improvements to the transportation planning process are warranted in order to enhance the suitability of the methods studied. The specific considerations addressed in the following sections 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 classified cities by population and auto availability.[7]

While auto availability was found to be highly correlated with trips per person it was also found that areas with high auto ownership rates generated fewer trips per person than areas with low auto ownership rates.[8] Consequently, the validity of this classification scheme is questionable because one would expect greater auto availability to lead to a greater number of trips being made.

Another method of classifying cities is according to their structure.[9] This technique measured 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 classified cities according to their dominant economic activity.[10,11,12,13,14] 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 of the area.

The fourth method of classifying cities[15,16] used factor analysis and cluster analysis 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. This procedure should result in cities very similar according to the measures used as input to the classification scheme being grouped together. 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 which directly associate with differences in trip generation activity. Consequently there is no method 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 1) the incompatibility between the models developed here with Virginia data and those given in the FHWA report, and 2) 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 from a wide range of cities that are based on the same parameters are available.

In the interim, transportation planners are encouraged to attempt to transfer models using intuitive schemes which derive inferences from available data such as population, economic activity, and unique areal characteristics.

Local versus Synthetic Models

A number of problems are encountered when the planner attempts to transfer transportation forecasting models. For instance, models calibrated with local data are more accurate than borrowed models, but the cost of local data may outweigh the benefits of increased accuracy. 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 extreme caution because of the multiple sources of potential error that can affect the projected volumes. In addition to the possiblility of erroneous estimates of trip ends, the flows resulting from borrowed parameters for the trip distribution model may be wrong, as may the route assignment rule that is used. Thus, if the simulated flows do not agree with the observed values, it is nearly impossible to specify the source of error (and conversely there are various options available to make the simulated flows correspond with the observed).

A fourth possible problem in borrowing models is that the variables used in the borrowed model must be available locally and must be easily forecasted. A large number of cross classification models use auto ownership and income as the independent variables. These models are currently difficult to use in Virginia where income information is not directly available. Although income might be synthesized from auto ownership or housing values, this process requires additional assumptions which may decrease the accuracy of the trip generation model.

Aggregate versus Disaggregate

Another technical consideration in this study concerns the application of a disaggregate model with aggregated data. The cross classification curves are calibrated on disaggregate household data but are applied with aggregated zonal averages. In order for zonal averages to adequately represent the zone, the characteristics of the zone must exhibit very little variation, which is generally not the case. Much of the variance in data which can be accounted for in the disaggregate model is lost when data are aggregated to the zonal level. When using zonal averages 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 as is shown in Figure 1. In Roanoke the average household size was 3.23 persons and the trip rate corresponding to this houshold size was 8.21 trips per household; however, the average number of trips per household was only 7.60, which resulted in estimates of the total trip productions being 8% high. When using a disaggregate model 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.

METHODOLOGY

In order to transfer a travel forecasting model between selected cities it was necessary to have some basis for accepting the model as being suitable. Accordingly, area classification schemes were examined in the hope that a set of city characteristics could be established to show where models were transferable. Cross classification and aggregate and disaggregate regression trip production models were then calibrated for selected cities in Virgina. Each trip production model was evaluated for its ability to replicate planning data and the transferability of the models among the study areas was tested. Trip attraction models were calibrated using the methods of general trip attraction rates, regression equations, and land use trip rates. Validation tests were conducted on these models.

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.

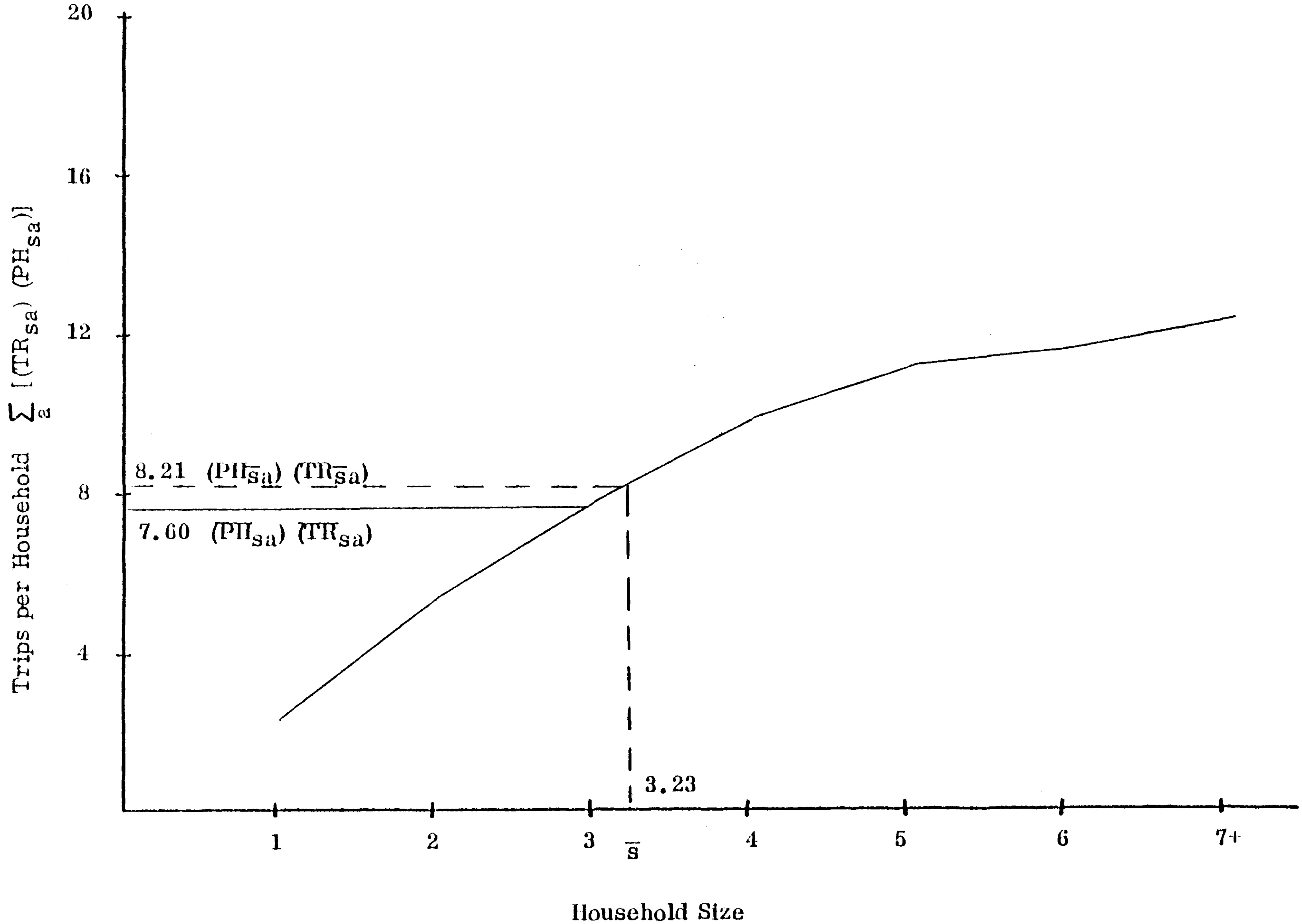

Figure 1. Trips per average household versus average trips per household in Roanoke.

The two explanatory variables were selected to be auto ownership and household size. Although income is highly recommended by the FHWA as one of the independent variables, it was not used in this study because it is not available in Virginia. Regression equations were also calibrated on the same disaggregate household data that the cross classification models were calibrated on so that the two methods could be directly compared.

Table 1

Characteristics of Selected Cities

City	1970 Population	Persons/ Per HH	Autos/ Per HH	Per Capita Income
Lynchburg	70,842*	3.02	1.140	$2,906
Roanoke	156,621*	2.97	1.224	$3,085
Harrisonburg	14,605	2.79	1.120	$2,742
Winchester	14,643	2.80	1.090	$2,954

*Urbanized area population.

Model Development

The cross classification matrices were calibrated using household and trip data obtained through O-D surveys. Household variables used were household size, auto ownership, and total number of trips reported. Trip data used were origin purpose and destination purpose. Once the matrices were calibrated, they were used in conjunction with planning data gathered by the Virginia Department of Highway and Tranportation to predict total person trip productions for the study areas.

The percent dwelling units and trips per dwelling unit by household size and car ownership distributions were first developed. These curves were both calibrated from the household data using auto ownership, household size, and number of trips reported. This was done by counting the number of households of each household size and auto ownership and by counting the number of trips reported by households in each household size and auto ownership classification. The percent dwelling units matrix was computed by dividing the number of dwelling units of a given household size and auto ownership by the total number of dwelling units with that household size. As a result, the percent of dwelling units for a given household size summed across all auto ownership categories is equal to 100%, or 1.000. The trips per dwelling unit by household size and car ownership matrix was computed by dividing the total number of trips reported by households of a given household size and auto ownership by the number of households of that size and auto ownership. Examples of the model matrices are shown in Table 2. The percent dwelling units curve and trip rate curve for Roanoke are shown in Figures 2 and 3 respectively.

Next the percent trips curve (percent of total trips by various trip purposes) was calibrated using both household data and trip data. Each trip record of the O-D survey was matched up with the corresponding household record. The trip purpose was determined from the purpose of origin and purpose of destination found on the trip record. The household size was taken from the household record. The trip was then added to the cell of the number of trips by household size and trip purpose matrix corresponding to its own purpose and household size. The percent trips matrix was computed by dividing the total number of trips of a given trip purpose and household size by the total number of trips by that household size. Again, in this manner the percent of trips for a given household size summed across trip purpose is equal to 100%, or 1.000. Examples of these matrices are shown in Table 3. The percent trip curve for Roanoke is shown in Figure 4.

Regression equations were also calibrated with the household data from the O-D survey. These household regression equations used household size and auto 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:

Household Regression Equations

Harrisonburg $R^2 = 0.6903$
Std. error of est./mean = 0.7709
TRIPS/HH = -1.48 + 1.85 x HH SIZE +3.35 x AUTO/HH

Roanoke $R^2 = 0.5076$
Std. error of est./mean = 0.7947
TRIPS/HH = -0.28 + 1.27 x HH SIZE + 3.06 x AUTOS/HH

Winchester $R^2 = 0.5909$
Std. error of est./mean = 0.7562
TRIPS/HH = -0.66 + 1.35 x HH SIZE + 3.54 x AUTOS/HH

Table 2

Roanoke Number of Households, Number of Trips
Percent of Households, Trip Rates

Roanoke
Number of Households

Autos Owned	1	2	3	4	5	6	7+	Total
	Household Size							
0	127	133	42	37	13	11	13	376
1	102	351	254	195	115	72	37	1,126
2+	2	182	179	208	127	54	25	777
Total	231	666	475	440	255	137	75	2,279

Roanoke
Number of Trips

Autos Owned	1	2	3	4	5	6	7+	Total
	Household Size							
0	188	248	151	93	53	33	63	829
1	313	1,972	1,861	1,663	1,105	788	403	8,105
2+	5	1,295	1,656	2,569	1,681	749	451	8,406
Total	506	3,515	3,668	4,325	2,839	1,570	117	17,340

Roanoke
Percent Households

Autos Owned	1	2	3	4	5	6	7+
	Household Size						
0	0.550	0.200	0.088	0.084	0.051	0.080	0.173
1	0.441	0.527	0.535	0.443	0.451	0.526	0.494
2+	0.009	0.273	0.377	0.473	0.498	0.394	0.333
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Roanoke
Trip Rates

Autos Owned	1	2	3	4	5	6	7+
	Household Size						
0	1.480	1.865	3.595	2.514	4.077	3.000	4.846
1	3.069	5.618	7.327	8.528	9.609	10.944	10.892
2+	2.500	7.115	9.251	12.351	13.236	13.870	18.040

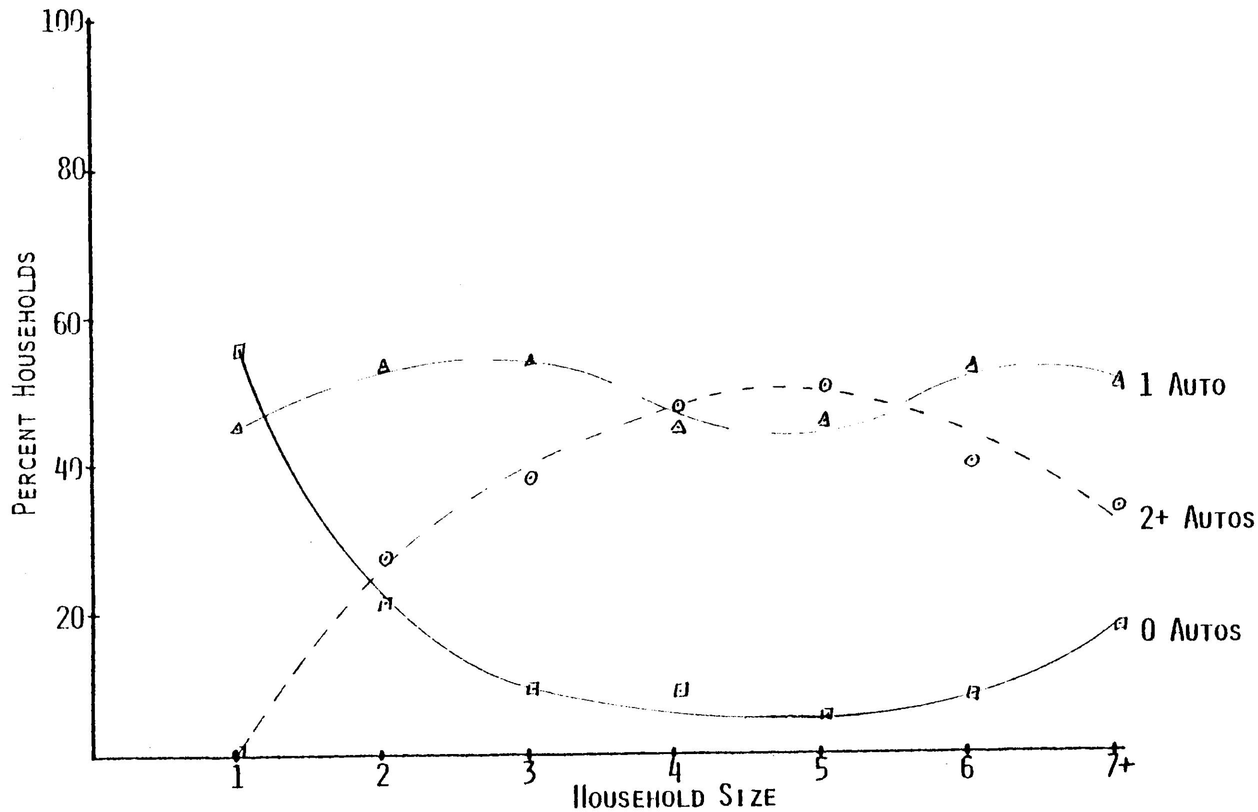

Figure 2. Roanoke percent households by auto ownership and household size.

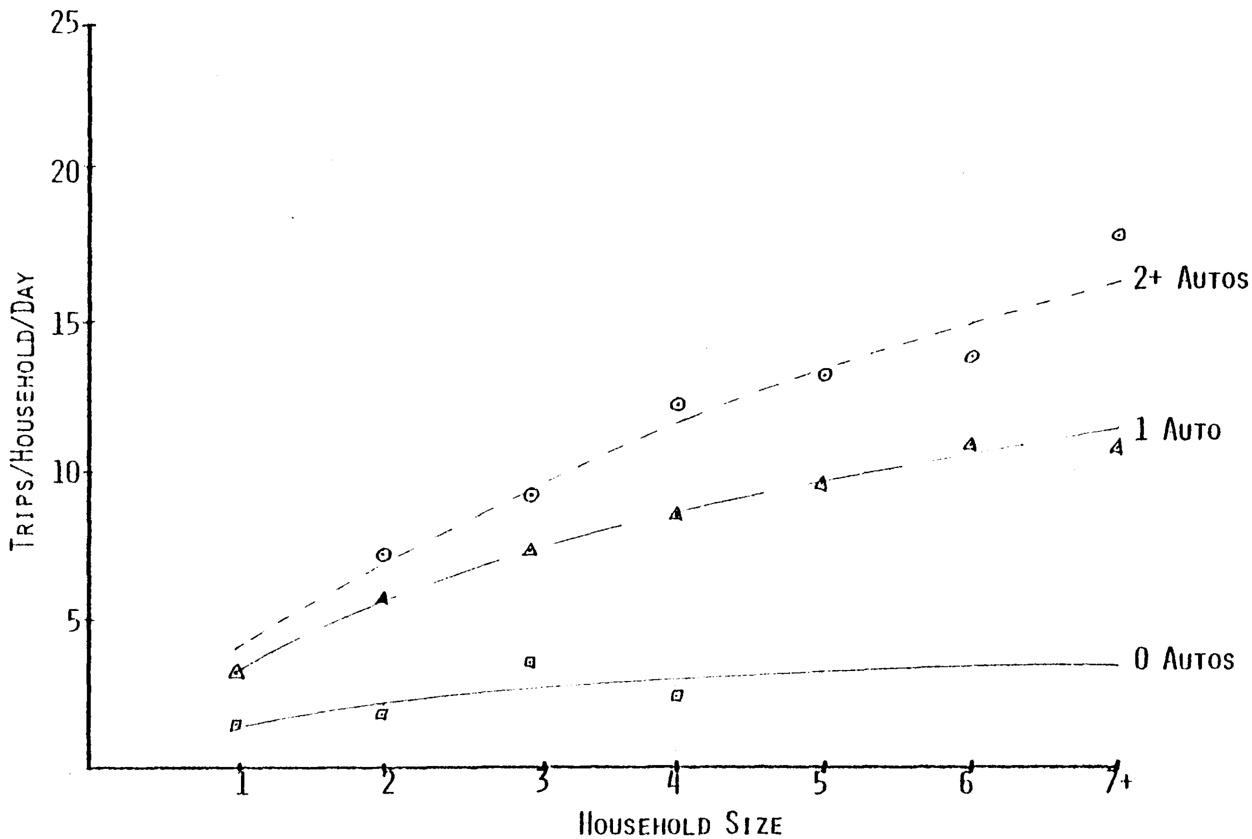

Figure 3. Roanoke trip rates by auto ownership and household size.

Table 3
Roanoke Number of Trips, Percent of Trips
by Trip Purpose

Roanoke
Number of Trips

Purpose	Household Size							
	1	2	3	4	5	6	7+	Total
Home-Based Work	122	987	938	869	588	389	199	4092
Home-Based Shop	72	484	499	593	361	161	153	2323
Home-Based School	0	7	62	110	99	34	12	324
Home-Based Other	184	1068	1137	1617	1109	611	355	6081
Non-Home-Based	89	654	731	834	496	255	155	3214
TOTAL	467	3200	3367	4023	2653	1450	874	16034

Roanoke
Percent of Trips

Purpose	Household Size						
	1	2	3	4	5	6	7+
Home-Based Work	0.261	0.309	0.279	0.216	0.222	0.268	0.228
Home-Based Shop	0.154	0.151	0.148	0.148	0.136	0.111	0.175
Home-Based School	0.0	0.002	0.018	0.027	0.037	0.024	0.014
Home-Based Other	0.394	0.334	0.338	0.402	0.418	0.421	0.406
Non-Home-Based	0.191	0.204	0.217	0.207	0.187	0.176	0.177
TOTAL	1.000	1.000	1.000	1.000	1.000	1.000	1.000

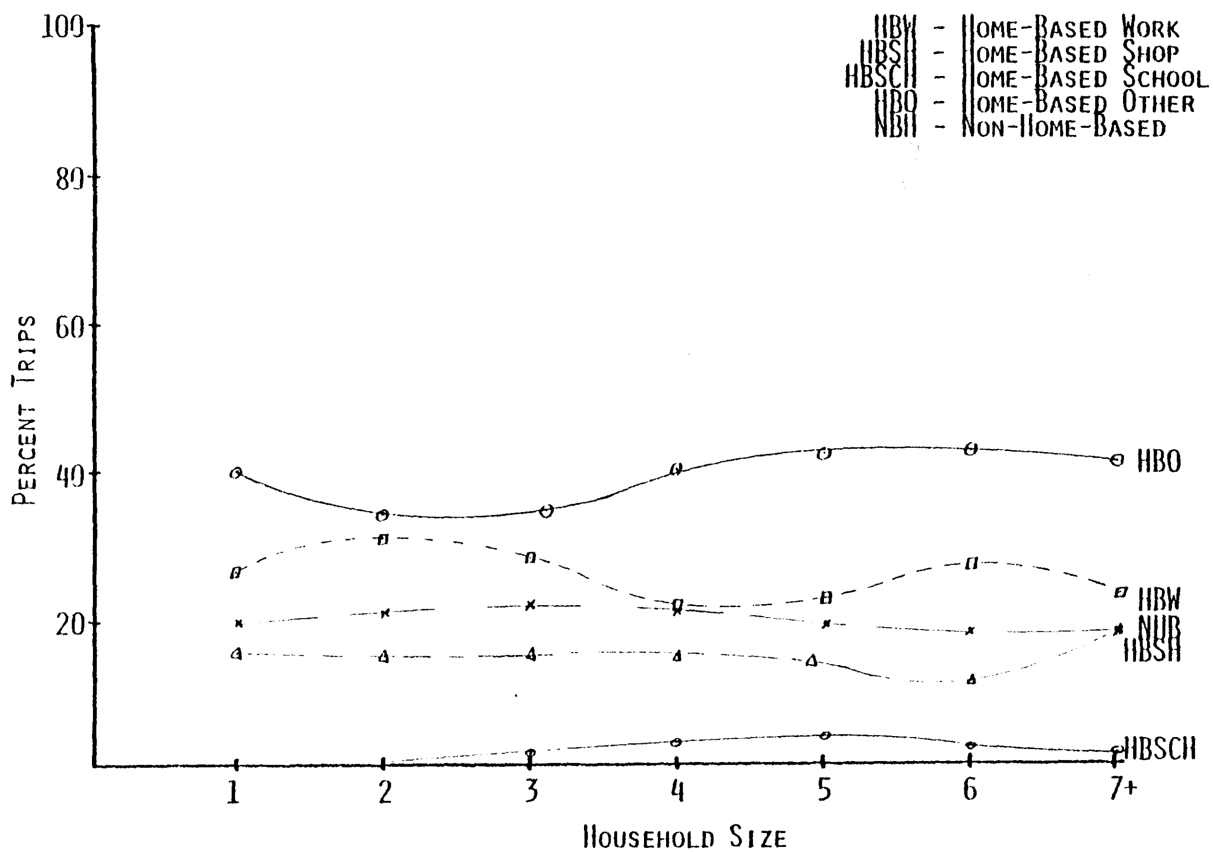

Figure 4. Roanoke percent trips by auto ownership and household size.

In addition to the cross classification matrices and disaggregate regression equations, regression equations were calibrated for Roanoke on aggregated data that was 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-and white-collar employment by zone of work. Unfortunately the number of retail employees was not available.

The home-based work, home-based other, and non-home-based productions and attractions by traffic zone for the base year (1965) were obtained from the Department. These were vehicle trips and not the desired person trips. The auto occupancy rates by trip purpose developed for Charlottesville were used to expand the vehicle trips to person trips. The occupancy rates are shown in Table 4. 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 number of trip attractions by trip purpose for each traffic zone was adjusted so that the total productions and attractions for each trip purpose were equal.

Table 4

Occupancy Rates Borrowed from Charlottesville

Home-Based Work	1.25
Home-Based Other	1.65
Non-Home-Based	1.35

Regression equations were then calibrated for each trip purpose. These equations for trip productions and attractions by each of the three trip purposes were then used to predict productions and attractions by each trip purpose for each traffic zone.

Calibrated Regression Equations
for Trip Productions

1. HBW Productions $R^2 = 0.88$ Std. error of est./mean = 0.353
   HBW P = 14.77 + 1.25 x AUTOS

2. HBO Productions $R^2 = 0.89$ Std. error of est./mean = 0.377
HBO P = -84.59 + 3.07 x AUTO

3. NHB Productions $R^2 = 0.90$ Std. error of est./mean = 0.728
NHB P = -5.75 + 1.25 x TOTEMP + 1.09 x DU

4. Total Production $R^2 = 0.93$ Std. error of est./mean = 0.628
Tot P = -47.63 + 5.12 x TOTEMP

These regression equations for Roanoke were calibrated on data aggregated to the zonal level.

Model Evaluations

The cross classification matrices and curves calibrated for the three study areas are given in Appendix A. The three matrices (percent dwelling units, trip rates, and percent trips) were then used with the household data in the O-D surveys to predict the reported trips. Trip productions were predicted by the cross classification and disaggregate regression models using both household data (from the O-D survey) averaged for the traffic zones (aggregated data) and summing predictions, by zones, for the individual household observations (disaggregate data). In both cases for all three study areas the distribution of predicted trips was found to be significantly different from the reported trips. The total predictions and chi-square values are shown in Table 5. These results indicate that even when using disaggregate data with the disaggregate models, the models do not perform accurately. This finding appears to indicate that auto ownership and household size alone do not adequately account for houshold travel behavior. It also points out that aggregated rates, even at a disaggregate level, are not sensitive to locational behavior. In addition to comparing actual trip productions reported in the O-D survey with trip productions predicted 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 6. The Winchester cross classification model transferred acceptably to both Raonoke 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 between which the models are to be transferred.

The cross classification models were also evaluated with expanded base year planning data aggregate to the zonal level. These results are shown in Table 7. The expectation that the

2006

Table 5

Calibrated Model Predictions

City	Total Reported Trips	Total Cross-class Predicted Trips	Chi-square For Cross-class Predicted Trips	Total Disaggregate Regression Predicted Trips	Chi-square for Disaggregate Regression Predicted Trips	# Degrees of Freedom	Chi-square Required for Significance at $\alpha = .05$
Disaggregate Data							
Roanoke	17,340	17,332	1,171	17,333	1,359	160	190
Winchester	11,298	11,295	405	11,298	460	50	67
Harrisonburg	9,174	9,117	599	9,346	819	96	119
Aggregated Data							
Roanoke	17,340	18,658	3,157	17,250	1,333	160	190
Winchester	11,298	11,801	1,004	11,274	453	50	67
Harrisonburg	9,174	9,091	1,767	9,299	798	96	119

Table 6

Transferred Model Predictions Using Disaggregate Data

City	Roanoke Cross-class Predicted Trips (chi-square)	Winchester Cross-class Predicted Trips (chi-square)	Harrisonburg Cross-class Predicted Trips (chi-square)	Roanoke Disaggregate Regression Predicted Trips (chi-square)	Winchester Disaggregate Regression Predicted Trips (chi-square)	Harrisonburg Disaggregate Regression Predicted Trips (chi-square)	# Degrees Of Freedom	Chi-square Required for Significance at $\alpha = .05$
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

Table 7

Transferred Cross Classification Models Using Aggregate Data

Models	Total Productions	Chi-Square	# Degrees of Freedom	Chi-Square Required for Significance at $\alpha = .05$
Roanoke			160	190
Calibrated Model	383,318	-		
Winchester Model	389,857	578		
Harrisonburg Model	436,390	9,776		
Winchester				
Calibrated Model	62,822	-	50	67
Roanoke Model	63,139	60		
Harrisonburg Model	68,619	672		
Harrisonburg			96	119
Calibrated Model	46,306	-		
Roanoke Model	43,521	320		
Winchester Model	43,553	362		

disaggregate cross classification models would not perform as well using aggregated data was found to be true as can been seen in the higher chi-square values (compare Tables 6 and 7). An example illustrating how the cross classification models were used with aggregated data and how the models were transferred is shown in Table 8.

A comparison of the predictive ability of the cross classification model versus the aggregate and disaggregate regression models for Roanoke is found in Table 9. 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 city-wide level (best total productions). This comparison used aggregated data because they were available from the Department. It is expected to be much more difficult to forecast data at the household level than at the zonal level and the accuracy of forecasted household data has to be determined before a direct comparison can be made; however, at this time it appears that models calibrated on aggregated zonal data perform better than models calibrated on disaggregate household data when used with forecast aggregated zonal data.

Table 8

Example Trip Production Calculations
Using Calibrated and Transferred Cross Classification Models

Example Study Area: Roanoke Traffic Zone 109

Characteristics

Population — 945
Dwelling Units — 281

Persons per dwelling unit = $\frac{945}{281}$ = 3.36

Simulate using	180	3 person households	540	persons
	101	4 person households	404	persons
	281	households	944	persons

Roanoke Calibrated Model

# Autos	# DU Household Size 3	4	X	Trip Rate Household Size 3	4	=	# Trips Household Size 3	4	
0	16	8		3.595	2.514		58	20	
1	96	45		7.327	8.528		703	384	
2+	68	48		9.251	12.351		629	593	
Total	180 +	101 = 281					1,390 +	997	= 2,387

Winchester Transferred Model

# Autos	# DU Household Size 3	4	X	Trip Rate Household Size 3	4	=	# Trips Household Size 3	4	
0	22	7		1.857	3.125		41	22	
1	94	54		7.366	9.947		692	537	
2+	64	40		9.471	13.021		606	521	
Total	180 +	101 = 281					1,339 +	1,080	= 2,419

Table 9

Cross Classification vs. Regression using Aggregate Data

Roanoke	Productions	Chi-Square (Compared with Actual)
Actual Productions	353,493	0
Cross Classification Productions	383,318	93,003
Aggregate Regression Productions	353,494	30,505
Disaggregate Regression Model Productions	353,957	57,294

Trip Attraction Analysis

For the analysis of trip attractions three techniques were considered. The first was the standard method recommended in the publication entitled Trip Generation Analysis issued by the FHWA, which utilizes general trip rates. A second method used the linear regression method, and the third involved specific land use trip rates to predict trip ends.

Trip Rate Procedures

The method for predicting trip attractions that is suggested in Trip Generation Analysis is described as "a simplified approach ...based upon the development of trip rates with a matrix". An example of the recommended trip rate matrix is shown in Table 10. The attractions for a particular trip purpose are calculated by multiplying the trip rate in a cell by the value of the variable at the top of the column and summing these products across the row to obtain total attractions for that trip purpose.

Table 10

Example of Procedure for Trip Attraction Estimates

Person Trip Attractions

Trip Purpose	Trips Per Household	Trips Per Employee				Univ.	High School	Other
		Non Retail	Retail					
			CBD	Shop Center	Other			
Home Based Work	—	1.70	1.70	1.70	1.70	—	—	—
Home Based Shop	—	—	—	9.00	4.00	—	—	—
Home Based School	—	—	—	—	—	0.90	1.60	1.20
Home Based Other	0.70	0.60	1.10	4.00	2.30	—	—	—
Non-Home Based*	0.30	0.40	1.00	4.60	2.30	—	—	—

Illustration data only, not to be used directly.

*Non-Home Based Productions and Attractions have the same rate and are used to allocate to zones the areawide control total developed in the trip production model.

Reprinted from: Trip Generation Analysis, Federal Highway Administration, Washington, D. C. August 1975, p. 41.

The trip attraction rates for the Virginia test cities, similar to those shown in Table 10, were calculated for each test city from planning data available from the Department. In computing the rates, the numbers of trips produced for the types of trip purposes were summed for all traffic zones to give a city-wide total of trip attractions by each purpose. Total trip attractions for each purpose were set equal to total trip productions because trip production methods are generally considered to be more accurate. The values of the socioeconomic variables (total employment, retail sales, number of housholds, number of students) were also summed for all traffic zones to get city-wide totals. The trip attraction rates were then computed as follows:

Home-Based Work Trip Rate	=	Total work trips/total employment
Home-Based Shopping Trip Rate	=	Total shopping trips/ total retail sales ($1,000's)
Home-Based School Trip Rate*	=	Total school trips/total students
Home-Based Other Trip Rate #1	=	36% of HBO trips/total households
HBOTR #2	=	64% of HBO trips/total employment
Non-Home-Based Trip Rate #1	=	20% of NHB trips/total households
NHBTR #2	=	45% of NHB trips/total retail sales ($1,000's)
NHBTR #3	=	35% of NHB trips/total employment

*If no student enrollment data were available, Home-Based School Trips were combined with Home-Based Other Trips

The matrix of trip rates calibrated for Roanoke is shown in Table 11. The trip rate matrices for all three study areas are given in Appendix B.

The home-based other and non-home-based trip attractions were computed from a number of rates because these types of trips are attracted to a variety of areas. The divisions used here were based on those developed in the Calhoun Area Transportation Study.(17)

Table 11

Roanoke

Trip Attraction Rates

	Trips/HH	Trips/Employee	Trips/$1,000 Retail Sales	Trips/Student
Home Based Work	—	1.471	—	—
Home Based Shop	—	—	0.195	—
Home Based School	—	—	—	0.0*
Home Based Other	1.046	1.321	—	—
Non-Home Based	0.331	0.412	0.126	—

*No school enrollment data available.

It was originally intended to base the home-based shopping trip on the number of retail employees instead of on total retail sales; however, the number of retail employees was not available. If retail employment data had been available, the home-based other trip rate #2 and the non-home-based trip rate #3 would have been based on non-retail employment instead of on total employment.

Regression Procedures

Attraction regression equations developed for Roanoke are shown below with the index of determination (R^2).

Calibrated Regression Equations for Trip Attractions

1. HBW Attractions $R^2 = 0.97$
   HBW A = 49.72 + 1.19 x TOTEMP

2. HBO Attractions $R^2 = 0.68$
   HBO A = 123.82 + 1.39 x TOTEMP + 1.18 x AUTOS

3. NHB Attractions $R^2 = 0.90$
   $NHB\ A = -5.75 + 1.26 \times TOTEMP + 1.09 \times DU$

4. Total Attractions $R^2 = 0.88$
   $TOTA = 196.22 + 3.81 \times TOTEMP + 2.47 \times DU$

Land Use Trip Rates

Another method of predicting trip attractions involves using 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.[5,6] In this method the number of units in each particular 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). This method is similar to conducting a special generator analysis for each traffic zone. The Department developed rates for a limited number of land uses. These Virginia rates were compared with the rates published by Arizona and ITE to determine which rates to use in this study.

Trip rates developed by Virginia were included in the Arizona study, and therefore can be directly compared with the overall rates in the Arizona study. Therefore, the average Virginia rates found in the Arizona study were used in the comparisons shown in Table 12. The rates from all three studies appear 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. It was assumed that Lynchburg would be included in the study at the time this analysis was performed. The procedure used is listed in Table 13. It was found that 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 photo, all units could be classified; thus the need for an on-site study was eliminated. The land use characteristics and trip end calculations for the selected traffic zones are shown in Table 14. The floor areas were measured on the area photos using the scale of the photograph, the dimensions of the building, and the number of floors.* This procedure is rather tedious and approximately 32 man-hours were required to classify the six traffic zones.

*The aerial photos for Roanoke were taken in January 1966 and Lynchburg's were taken in December 1968.

Table 12

Land Use Trip Rates Developed in Virginia As Compared with Arizona and ITE Trip Rates

LAND USE	Virginia	Arizona	ITE
1. Single Family Dwellings	11.1 trips/DU (21 studies)	9.9 trips/DU (352 studies)	10.0 trips/DU (208 studies)
2. Apartments	7.5 trips/DU (12 studies)	6.7 trips/DU (93 studies)	6.1 trips/DU (98 studies)
3. Shopping Centers			
a. Overall	40.6 trips/1000 GFA (17 studies) 22.1 trips/employee (17 studies)	39.3 trips/1000 GFA (143 studies) 21.0 trips/employee (86 studies)	
b. Zero generator shopping center	42.7 trips/1000 GFA (7 studies) 22.4 trips/employee (5 studies)	64.4 trips/1000 GFA (71 studies) 37.9 grips/employee (43 studies)	60.4 trips/1000 GFA (31 studies) (For shopping centers of 100000-199999 gross sq. ft.)
c. One generator shopping center	45.9 grips/1000 GFA (7 studies) 22.0 trips/employee (4 studies)	41.0 trips/1000 GFA (23 studies) 22.0 trips/employee (13 studies)	40-50 trips/1000 GFA approx. 42.5 trips/1000 GFA
d. Two + Generator shopping center	33.0 trips/1000 GFA (3 studies)	33.2 trips/1000 GFA (49 studies)	34.5 trips/1000 GFA (38 studies)
4. Offices			
a. Overall	9.1 trips/1000 GFA (2 studies)	13.4 trips/1000 GFA (50 studies)	
b. General offices	9.1 trips/1000 GFA (2 studies)	10.9 trips/1000 GFA (33 studies)	11.7 trips/1000 GFA (22 studies)

Table 13

Procedure for Estimating Trip Ends
Using Trip Rates from ITE Study
and Aerial Photographs

1. Select traffic zones for study. Should have at least

   1 residential zone
   1 shopping center
   1 zone in CBD

2. Obtain aerial photograph containing study traffic zone(s).

3. Outline traffic zone on photograph.

4. Count number (and size) of units in traffic zone by ITE classification systems. Estimate floor area from photograph scale and number of stories in building. Also count number of parking spaces.

5. Conduct on-site study to classify any questionable units.

6. Multiply units by rates.

7. Compare these trip ends with trip ends predicted using regression and cross classification.

Table 14

Land Use Trip Rate Calculations for Study Zones

Roanoke

TZ1

286 DU	@ 10.0 trips/DU	2860
425 hotel rooms	@ 11.3 trips/room	4802
155,600 $ft.^2$ office	@ 11.69 trips/1000 $ft.^2$	1819
82,170 $ft.^2$ manufacturing	@ 4.10 trips/1000 $ft.^2$	337
3 gas stations	@ 748 trips/station	2244
		12,062 trip ends

TZ67

1083 DU	@ 10.0 trips/DU	10830
15,760 $ft.^2$ restaurant	@ 164.4 trips/1000 $ft.^2$	2591
22,040 $ft.^2$ warehousing	@ 5.01 trips/1000 $ft.^2$	110
58,120 $ft.^2$ office	@ 11.69 trips/1000 $ft.^2$	679
710 elementary students	@ 0.51 trips/student	362
		14,572 trip ends

TZ151

205,302 $ft.^2$ shopping center	@ 49.9 trips/1000 $ft.^2$	10,244 trip ends

Trip rates obtained from: Trip Generation, Institute of Traffic Engineers, Arlington, Virginia, 1976

2018

Table 14 (cont'd)

Land Use Trip Rate Calculations for Study Zones

Lynchburg

TZ11

367 DU	@ 10.0 trips/DU	3670
6.89 acre industrial	@ 59.9 trips/acre	413
15,000 ft.^{2} manufacturing	@ 4.10 trips/1000 ft.^{2}	62
68,750 ft.^{2} warehousing	@ 5.01 trips/1000 ft.^{2}	344
		4,489 trip ends

TZ20

135 DU	@ 10.0 trips/DU	1350
36 apartments	@ 6.1 trips/apt	220
412 elementary students	@ 0.51 trips/student	210
		1,780 trip ends

TZ34

2,532 high school students	@ 1.22 trips/student	3089
467,950 ft.^{2} shopping center	@ 47.6 trips/1000 ft.^{2}	22274
56 DU	@ 10.0 trips/DU	560
4 apartments	@ 6.1 trips/apt.	24
2527 ft.^{2} warehousing	@ 5.01 trips/1000 ft.^{2}	13
		25,960 trip ends

Trip rates obtained from: Trip Generation, Institute of Traffic Engineers, Arlington, Virginia, 1976

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

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 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 15. The high percent error for traffic zone 20 of Lynchburg would indicate the need for special generator analysis or 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 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.

Table 15

Comparison of Actual Productions and Attractions
with Predictions Using Cross Class, Regression, and Land Use Trip Rates

Study Zone	Actual Productions and Attractions	Land Use Trip Ends	% Error	Cross Class Productions and Attractions	% Error	Regression Productions and Attractions	% Error
Roanoke	(1965)	(1966)		(1965)		(1965)	
TZ1	10,414	12,062	15.8%	17,587	68.9%	15,918	52.8%
TZ67	14,397	14,572	1.2%	15,405	7.0%	15,003	4.2%
TZ151	8,519	10,244	20.2%	1,718	-79.8%	1,646	-80.7%
Lynchburg	(1965)	(1968)					
TZ11	4,165	4,489	7.8%	-	-	-	-
TZ20	3,478	1,780	-48.8%	-	-	-	-
TZ34	25,862	25,960	0.4%	-	-	-	-

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APPENDIX A

Cross Classification Models

2024

ROANOKE

Cross Classification Matrices

ROANOKE

PERCENT HOUSEHOLDS

AUTOS OWNED	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
0	0.550	0.200	0.088	0.084	0.051	0.080	0.173
1	0.442	0.527	0.535	0.443	0.451	0.526	0.493
2	0.009	0.273	0.377	0.473	0.498	0.394	0.333

ROANOKE

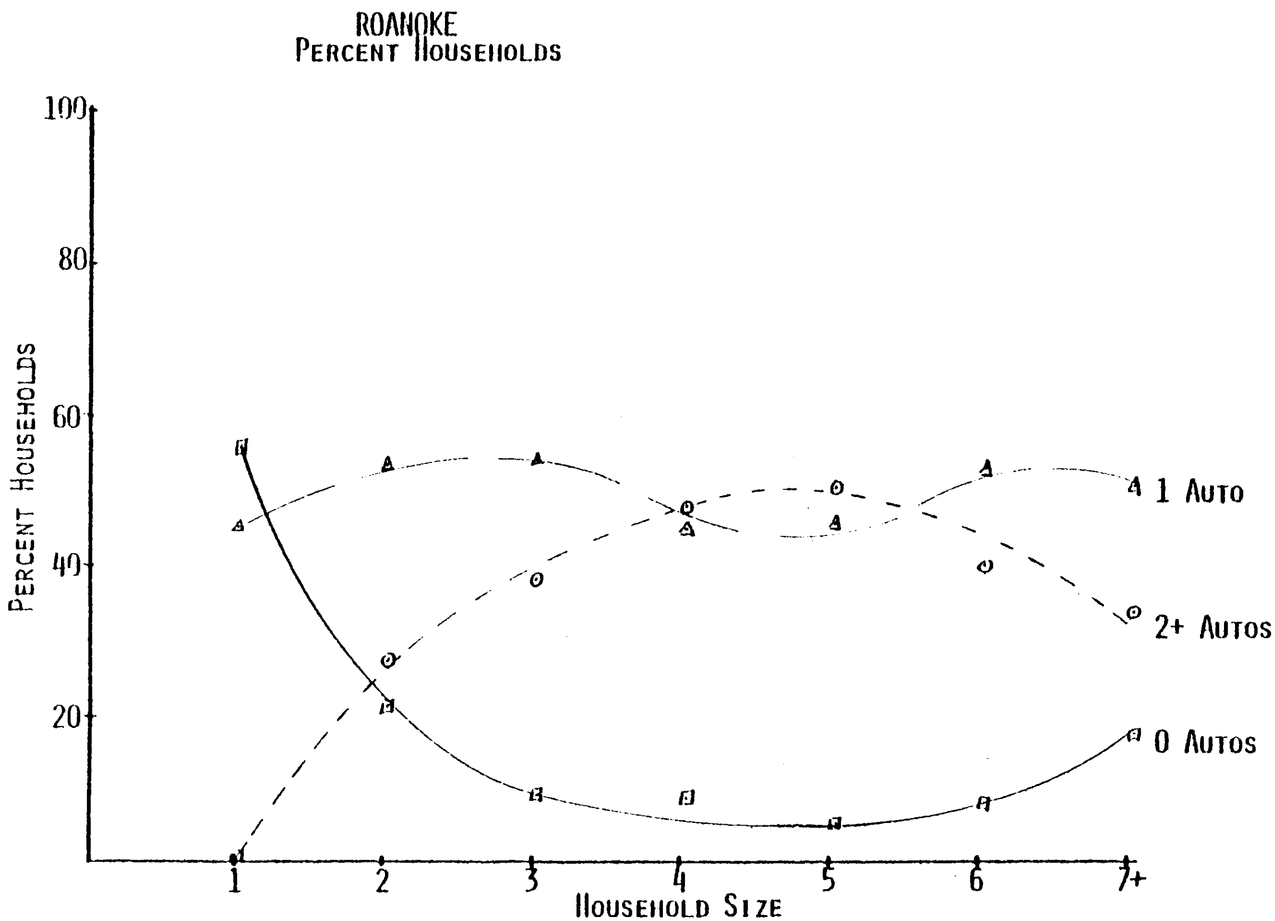
TRIP RATE

AUTOS OWNED	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
0	1.480	1.865	3.595	2.514	4.077	3.000	4.846
1	3.069	5.618	7.327	8.528	9.609	10.944	10.892
2	2.500	7.115	9.251	12.351	13.236	13.870	18.040

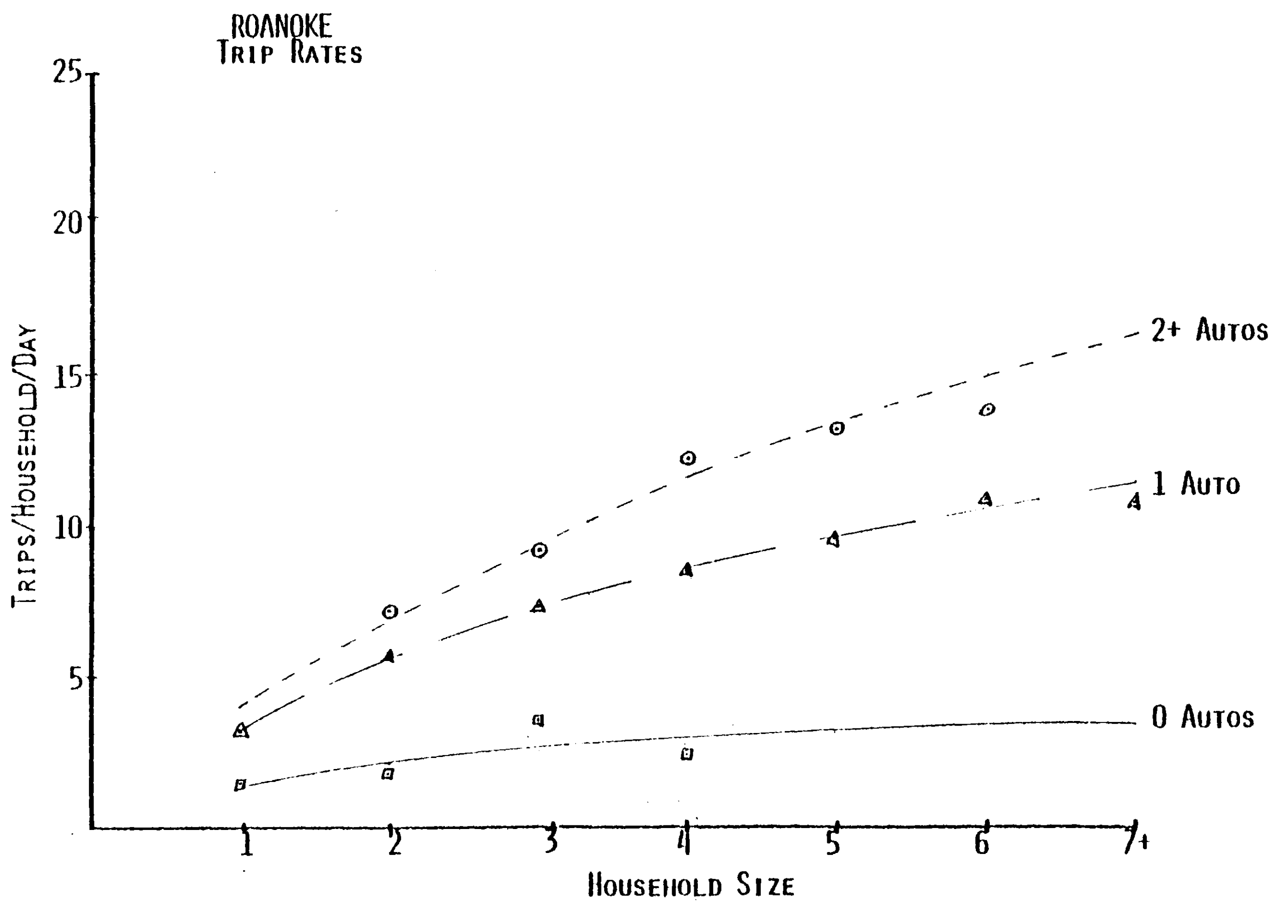
TRIP PURPOSE

PURPOSE	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
HOME-BASED WORK	0.261	0.308	0.279	0.216	0.222	0.268	0.228
HOME-BASED SHOP	0.154	0.151	0.148	0.147	0.136	0.111	0.175
HOME-BASED SCHOOL	0.0	0.002	0.018	0.027	0.037	0.023	0.014
HOME-BASED OTHER	0.394	0.334	0.338	0.402	0.418	0.421	0.406
NON-HOME-BASED	0.191	0.204	0.217	0.207	0.187	0.176	0.177

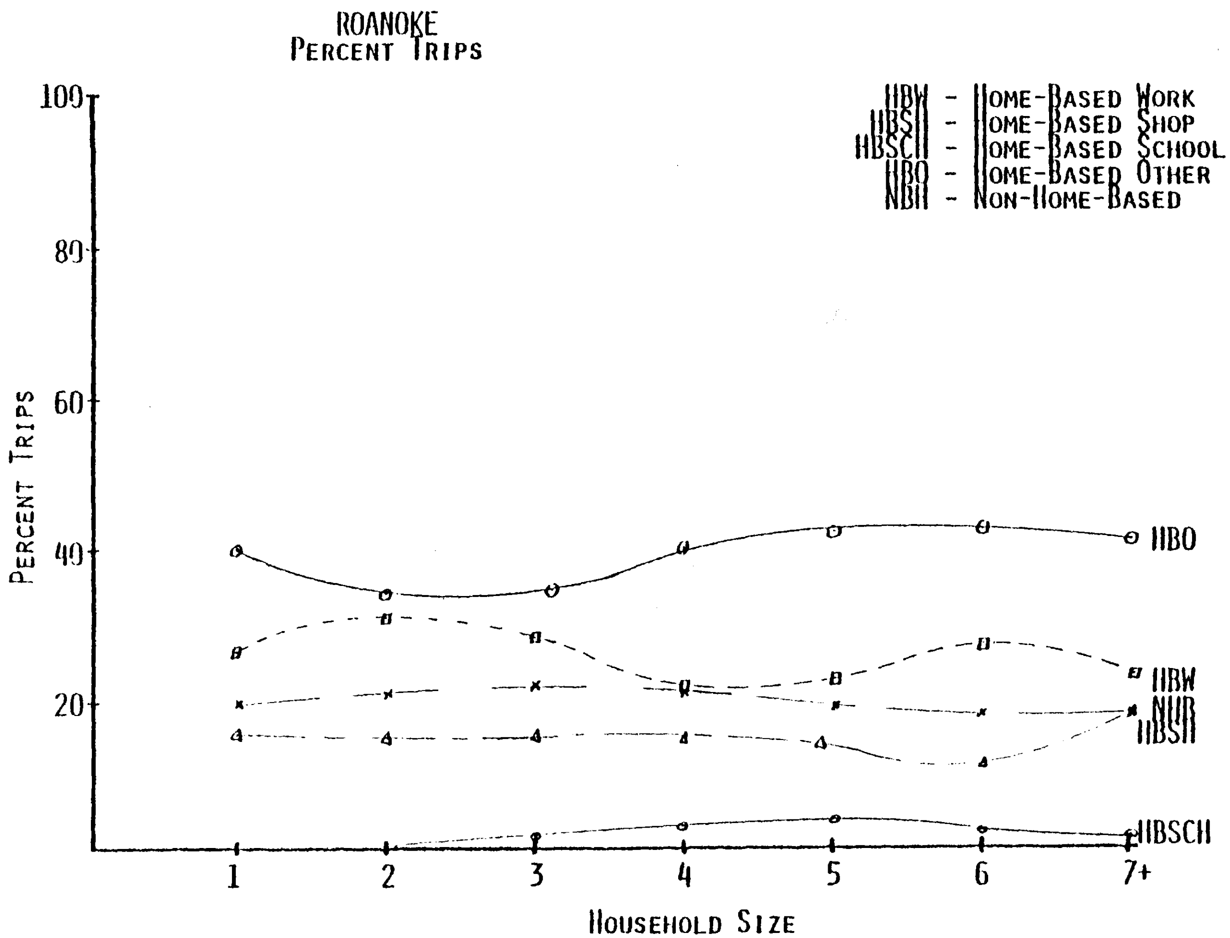
Roanoke Percent Households by Auto Ownership and Household Size



Roanoke Trip Rates by Auto Ownership
and Household Size



Roanoke Percent Trips by Auto Ownership
and Household Size



2027

2028

HARRISONBURG

Cross Classification Matrices

HARRISONBURG

PERCENT HOUSEHOLDS

AUTOS OWNED	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
0	0.550	0.248	0.107	0.060	0.067	0.196	0.563
1	0.440	0.479	0.427	0.324	0.337	0.392	0.146
2	0.009	0.273	0.467	0.615	0.596	0.412	0.292

HARRISONBURG

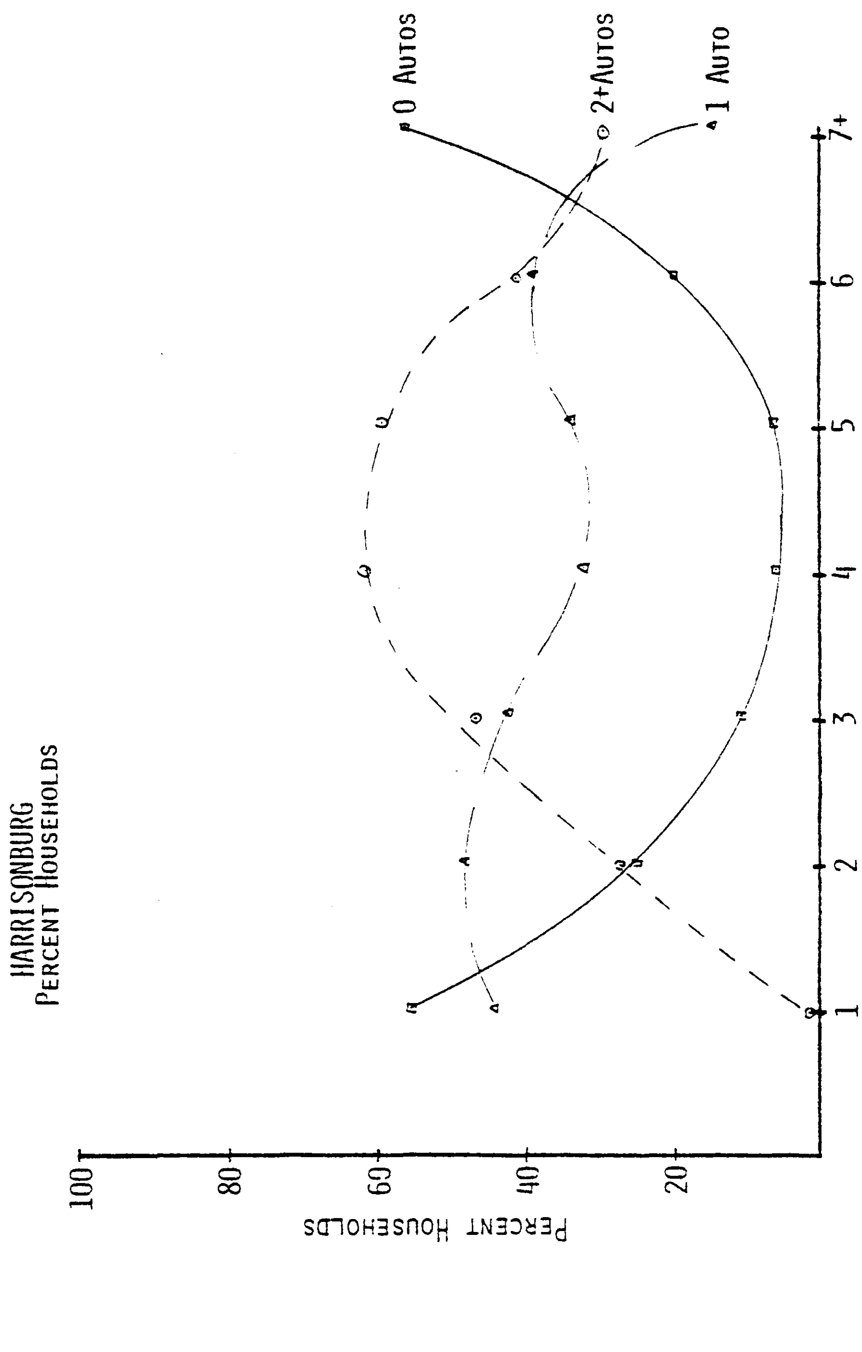
TRIP RATE

AUTOS OWNED	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
0	0.367	0.505	0.958	2.273	4.571	3.500	0.296
1	3.104	5.708	7.708	10.424	9.771	11.600	16.714
2	3.000	8.153	10.219	14.821	17.887	19.095	24.643

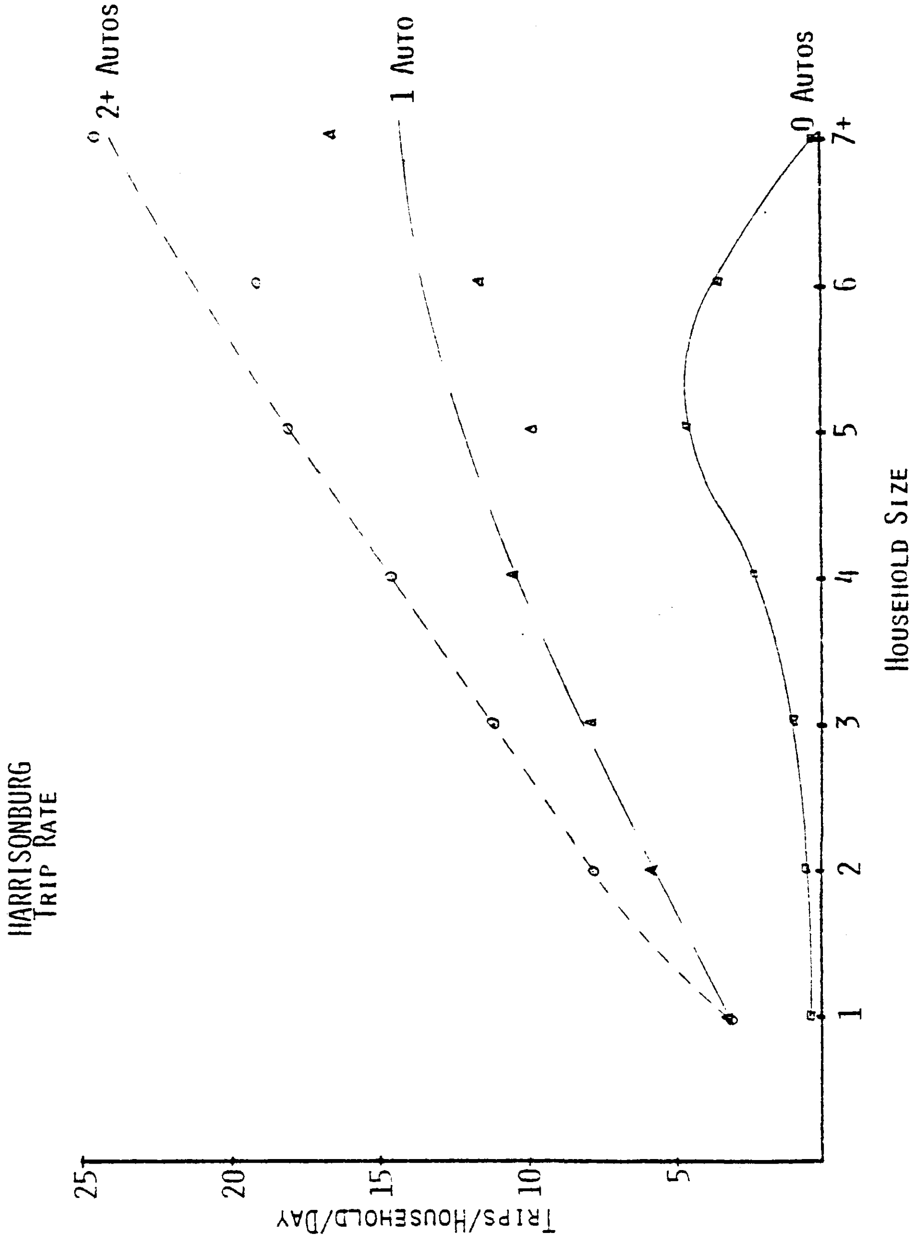
HARRISONBURG

TRIP PURPOSE

PURPOSE	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
HOME-BASED WORK	0.270	0.304	0.272	0.190	0.181	0.221	0.142
HOME-BASED SHOP	0.137	0.115	0.115	0.096	0.050	0.057	0.106
HOME-BASED SCHOOL	0.034	0.031	0.091	0.131	0.172	0.245	0.200
HOME-BASED OTHER	0.330	0.313	0.320	0.353	0.357	0.315	0.334
NON-HOME-BASED	0.229	0.237	0.202	0.229	0.240	0.163	0.218


HARRISONBURG
PERCENT HOUSEHOLDS
0 AUTOS
2+AUTOS
1 AUTO
PERCENT HOUSEHOLDS
100
80
60
40
20
1
2
3
4
5
6
7+
HOUSEHOLD SIZE

2030



HARRISONBURG
TRIP RATE
2+ AUTOS
1 AUTO
0 AUTOS
TRIPS/HOUSEHOLD/DAY
25
20
15
10
5
1
2
3
4
5
6
7+
HOUSEHOLD SIZE

2032

WINCHESTER
Cross Classification Matrices

WINCHESTER

PERCENT HOUSEHOLDS

AUTOS OWNED	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
0	0.601	0.170	0.120	0.066	0.050	0.068	0.023
1	0.383	0.589	0.524	0.541	0.528	0.420	0.523
2	0.016	0.242	0.356	0.393	0.422	0.511	0.455

WINCHESTER

TRIP RATE

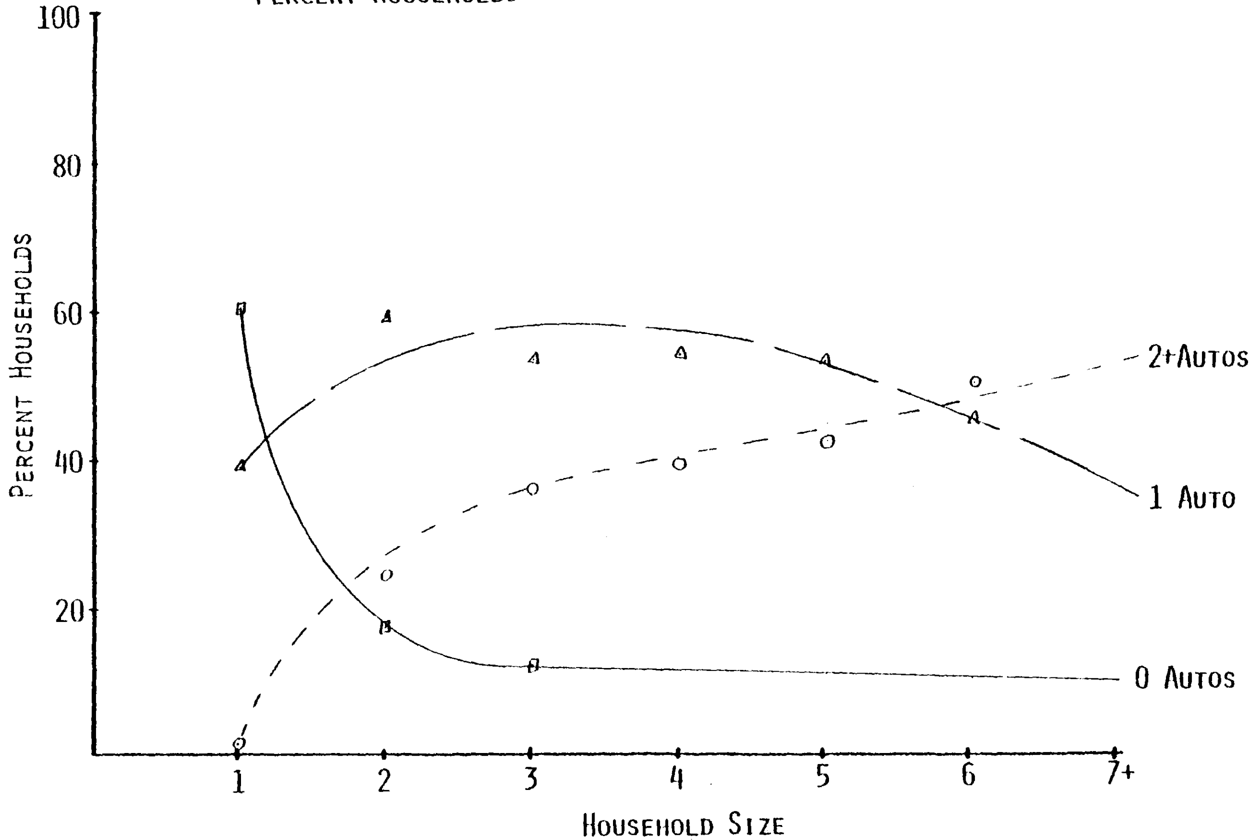
AUTOS OWNED	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
0	1.128	1.014	1.857	3.125	5.625	1.667	0.0
1	3.916	5.577	7.366	9.947	9.129	10.486	9.087
2	5.250	8.762	9.471	13.021	15.515	17.267	19.050

WINCHESTER

TRIP PURPOSE

PURPOSE	HOUSEHOLD SIZE 1	2	3	4	5	6	7+
HOME-BASED WORK	0.212	0.331	0.299	0.232	0.179	0.195	0.228
HOME-BASED SHOP	0.089	0.116	0.117	0.104	0.107	0.122	0.116
HOME-BASED SCHOOL	0.062	0.011	0.070	0.114	0.154	0.180	0.216
HOME-BASED OTHER	0.315	0.303	0.325	0.319	0.366	0.330	0.327
NON-HOME-BASED	0.322	0.239	0.189	0.231	0.194	0.172	0.113

WINCHESTER
PERCENT HOUSEHOLDS



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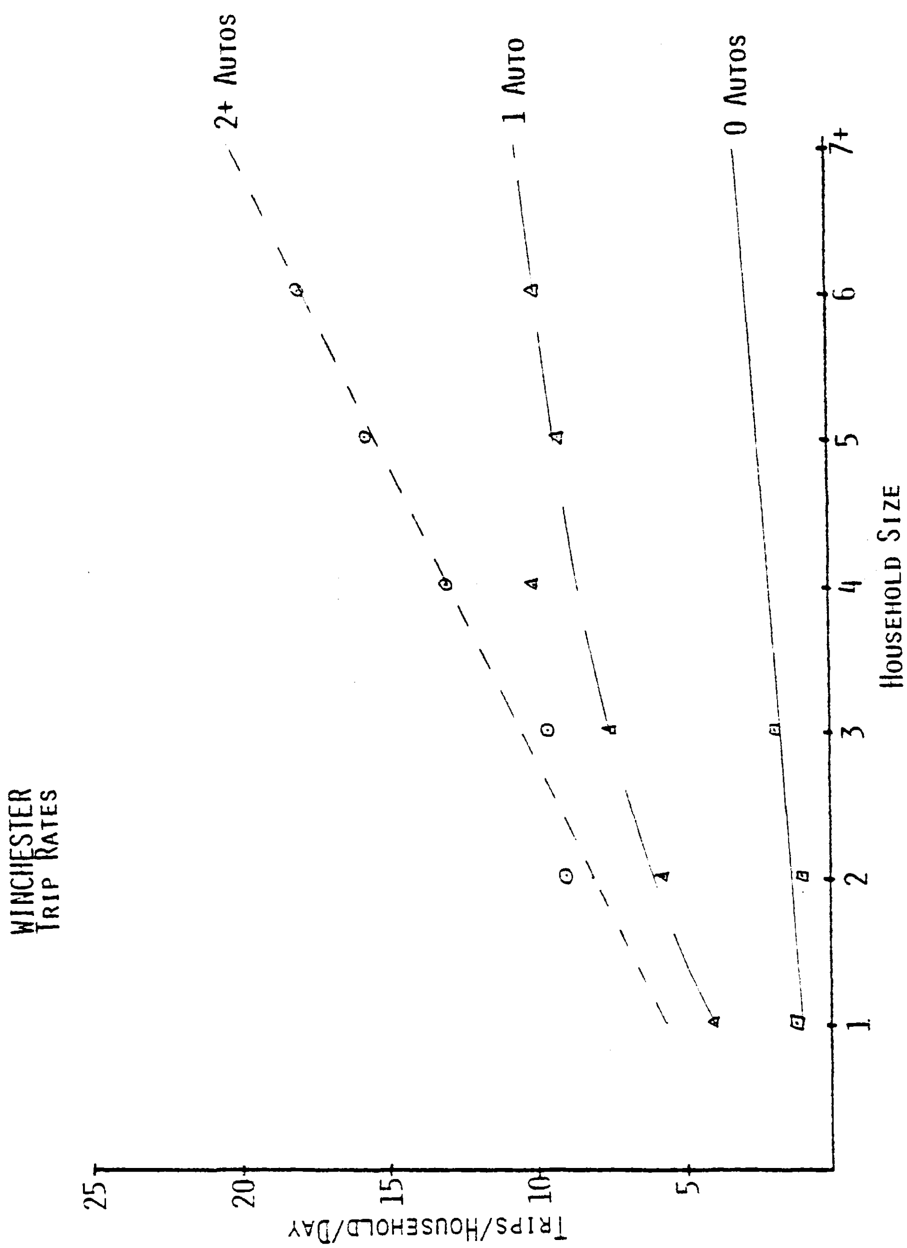
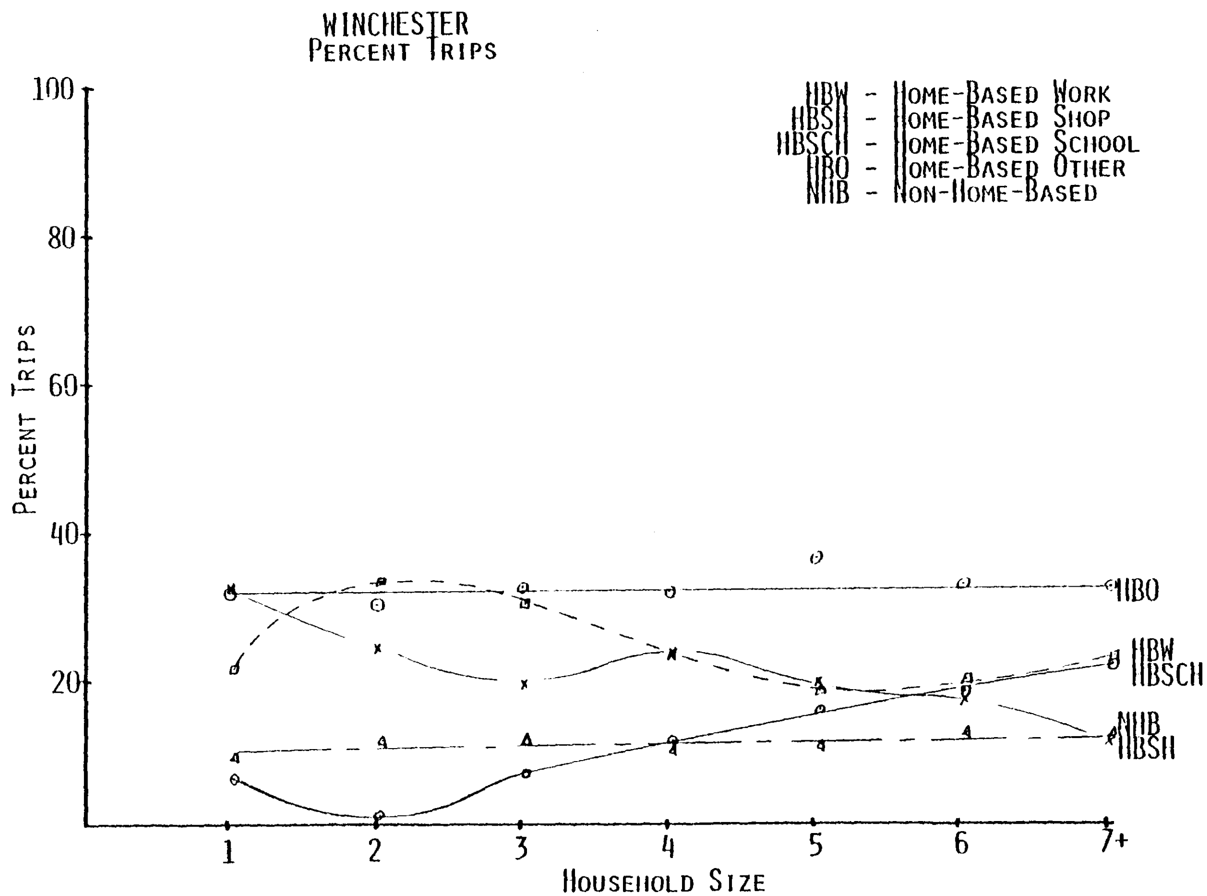

WINCHESTER
TRIP RATES
2+ AUTOS
1 AUTO
0 AUTOS
TRIPS/HOUSEHOLD/DAY
25
20
15
10
5
1
2
3
4
5
6
7+
HOUSEHOLD SIZE


WINCHESTER
PERCENT TRIPS
HBW - HOME-BASED WORK
HBSH - HOME-BASED SHOP
HBSCH - HOME-BASED SCHOOL
HBO - HOME-BASED OTHER
NHB - NON-HOME-BASED
PERCENT TRIPS
100
80
60
40
20
1
2
3
4
5
6
7+
HOUSEHOLD SIZE
HBO
HBW
HBSCH
NHB
HBSH

APPENDIX B

Trip Attraction Rate Tables

ROANOKE

Trip Attraction Rates

	Trips/HH	Trips/Employee	Trips/$1000 Retail Sales	Trips/Student
Home Based Work	--	1.471	--	--
Home Based Shop	--	--	0.195	--
Home Based School	--	--	--	0.0*
Home Based Other	1.046	1.321	--	--
Non-Home Based	0.331	0.412	0.126	--

*No school enrollment data available.

HARRISONBURG

TRIP ATTRACTION RATES

	TRIPS/HH	TRIPS/EMPLOYEE	TRIPS/$1000 RETAIL SALES	TRIPS/STUDENT
HOME BASED WORK	--	0.896	--	--
HOME BASED SHOP	--	--	0.052	--
HOME BASED SCHOOL	--	--	--	0.0*
HOME BASED OTHER	1.218	0.921	--	--
NON-HOME BASED	0.336	0.250	0.044	--

*NO SCHOOL ENROLLMENT DATA AVAILABLE.

WINCHESTER

Trip Attraction Rates

	Trips/HH	Trips/Employee	Trips/$1000 Retail Sales	Trips/Student
Home Based Work	--	1.167	--	--
Home Based Shop	--	--	0.083	--
Home Based School	--	--	--	0.0*
Home Based Other	1.083	1.017	--	--
Non-Home Based	0.308	0.285	0.066	--

*No school enrollment data available.