Evaluation of the Transferability of Trip Generation Models from One Urban Area to Another

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A study was conducted to test the transferability of vehicle trip generation models from one urban area to another as opposed to using an origin-destination model for small urban areas with populations less than 250,000. The validity of each set of calibrated trip generation models was measured by the ability of the trip generation-trip distribution-traffic assignment process to duplicate traffic volumes on the street system of the urban area of Fayetteville, North Carolina. The developmental procedures for the synthesized vehicle trip productions used cross-classification analysis, a technique that specifies trip production as a function of two or more independent variables. These independent variables were related to the socioeconomic characteristics of the dwelling unit. The dependent variable was the vehicle trips produced by the dwelling unit. Regression analysis was used to develop the trip attractions. Based on the tests conducted in the study, the synthesized trip generation model was found to give essentially the same results as the origin-destination trip generation model. Therefore, it was concluded that the synthesized models adequately duplicated travel volumes in urban areas of similar size and thus that trip generation models are transferable from one urban area to another when the urban areas are of similar size.

In an urban transportation study, one of the most costly and time-consuming phases is the inventory of existing travel patterns. This inventory includes the number of trips that originate in each analysis unit, the number of trips destined to each analysis unit, the purpose of the trips, and the characteristics of the movement, such as the routes used. Data from this inventory describe existing conditions and help to identify current deficiencies in the transportation system. From these data, transportation engineers and planners determine the travel characteristics used in developing models to predict future transportation requirements.

Considerable time and expense are involved in conducting the survey, checking the accuracy of the data, analyzing the source of travel, and developing and calibrating the travel prediction models. The cost of inventorying existing travel patterns in North Carolina's small urban areas has been as much as 80 percent of the total cost of a transportation study. The inventory phase adds an additional 2 years to the length of a transportation study for urban areas with populations between 50,000 and 250,000.

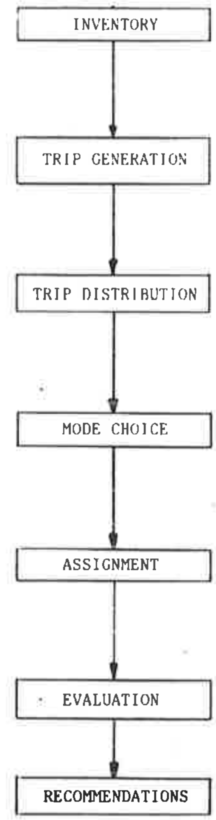
TRANSPORTATION PLANNING PROCESS

The transportation planning process as it is now established in all metropolitan areas is a formal set of models for estimating travel demand. The basic structure of the travel demand process is shown in Figure 1.

The inventory phase shown in Figure 1 is the base on which the process rests and includes, in addition to an inventory of existing travel patterns, surveys of economic activity and population, measures of land use, and inventories of existing transportation facilities. Trip generation models and trip distribution models are developed from the inventory of travel patterns (origin-destination survey and traffic counts). Population and economic activity (usually expressed in terms of employment and income) serve as input to the trip generation models. The land use inventory (usually expressed by population and employment distribution) is another input to the trip generation models.

Trip generation bridges the gap between land use and travel by providing the means by which the number of trips that begin or end in a given analysis unit can be related to the socioeconomic or land use characteristics of that unit. The generated trip ends form the measures of trip origins and trip destinations that are used in the trip distribution model, along with the degree of spatial separation developed from the highway and transit facility inventory, to model travel patterns. These resulting travel patterns are then assigned to the highway or transit systems in the traffic assignment phase.

Figure 1. Basic structure of urban travel demand forecasting process.



In the evaluation phase, many alternative land use plans and transportation systems can be evaluated. The objective of the urban transportation planning process is to provide the information necessary for making decisions on when and where improvements should be made in transportation systems in order to satisfy travel demands and promote land development patterns that are consistent with community goals and objectives.

RESEARCH OBJECTIVE

The specific objective of this study is to develop vehicle travel prediction models for small urban areas (populations less than 250,000) that can be transferred from one urban area to another with an acceptable degree of accuracy. The independent variables to be used in these models are household size, automobiles per household, income per household, number of households, and employment. These models predict vehicle trips per day as a function of the preceding independent variables. If the models developed for one urban area can be transferred to another urban area, the cost of transportation planning studies can be reduced by as much as 80 percent.

METHODOLOGY

The three data bases used in the research were comprehensive traffic counts for the Fayetteville, North Carolina, street system, the Fayetteville origin-destination study, and the composite data cross-classification models based on the merging of origin-destination survey data files for Greensboro, High Point, and Gastonia, North Carolina. Trip generation models were developed from the Fayetteville origin-destination study and the composite cross-classification models. The comprehensive traffic counts were used to test the accuracy of each model to duplicate existing traffic volumes on the Fayetteville street system.

The Fayetteville origin-destination models used trip rate analysis for productions and regression analysis for attractions. The composite (synthesized) trip generation model used cross-classification models for productions and regression analysis for attractions. The synthesized regression models for attractions were developed from the Greensboro survey data.

Study Area

Inventories of travel patterns have been collected by the North Carolina Department of Transportation (DOT) for the cities of Fayetteville, Greensboro, High Point, and Gastonia. Based on these inventories trip generation models have been developed and evaluated for their accuracy in synthesizing trip generation for Fayetteville.

Data Base

The data base is composed of three separate elements: (a) comprehensive 1977 traffic counts for the street system of the Fayetteville urban area, (b) the 1969 Fayetteville origin-destination study, and (c) a composite model developed from the Greensboro, High Point, and Gastonia transportation studies.

Comprehensive Traffic Counts

In March 1977 comprehensive 24-hr traffic counts were taken for the street system of the Fayetteville urban area. The counts were taken for all major streets in the Fayetteville urban area. These traffic counts were used as a comparison with the assigned link volumes of the Fayetteville origin-destination model and the synthesized model.

Fayetteville Origin-Destination Study

Origin-Destination Productions and Attractions

In June 1969 the North Carolina State Highway Commission (now the North Carolina DOT) conducted a comprehensive home interview origin-destination traffic survey in Fayetteville. The planning area was divided into 14 districts and further divided into 196 zones. The external cordon delineating the planning area had 29 entry stations.

The models used in this procedure were trip rate analysis and regression analysis (1). The independent variables used in these models were housing condition, race, employment, and number of households. The dependent variable was vehicle trips per day.

Internal trips are those trips in which both origin and destination are located in the planning area. A three-trip-purpose distribution consisting of home-based work trips, other home-based trips, and non-home-based trips was used in classifying all trips.

Origin-destination internal vehicle trip productions were estimated on a zonal basis in four categories: (a) trips produced by dwelling units, (b) trips produced by commercial passenger cars, (c) trips produced by trucks, and (d) trips produced by taxi. Dwelling-unit trip generation rates are given in Table 1 (1, p. 24). Commercial trip generation rates are as follows:

Vehicle Type	Generation Rate (vehicle trips/day)
Commercial	7.4
Truck	7.4
Taxi	40.0

The home-based work-trip-attraction factor for zones was assumed to be total zonal employment. Trip-attraction factors for other home-based trips and non-home-based trips were assumed to be the same and were determined by multiple regression analysis. Total external trip ends were used as the dependent variable and industrial employment, retail and wholesale employment, highway-related retail employment, office employment, service employment, and dwelling units as the independent variables. Statistical tests of significance of the regression analysis were met and are given in Table 2 (1). The resultant regression equation was as follows:

$$Y = 33.93184 + 0.44378X_1 + 2.78768X_2 + 1.84756X_3 + 0.72887X_4 + 0.19708X_5 \quad (1)$$

where

X_1 = industrial employment,
X_2 = wholesale-retail employment,
X_3 = highway retail employment,
X_4 = service employment, and
X_5 = dwelling units.

External trips are those trips in which either

Table 1. Dwelling-unit trip generation rates.

Race	Housing Condition	Generation Rate (vehicle trips/day)
White	Above average	8.8
White	Average	7.8
White	Below average	4.2
Nonwhite	Above average	5.2
Nonwhite	Average	3.0
Nonwhite	Below average	2.3

Table 2. Elements of regression development.

Variable	Standard Error of Coefficient	T-Value	Coefficient
X_1	0.05328	8.32905	0.44378
X_2	0.10215	27.28873	2.78768
X_3	0.18379	10.05279	1.84756
X_4	0.10354	7.39756	0.72887
X_5	0.03808	5.17539	0.19708

Note: Multiple R = 0.9682, SEE = 87.8996, and SEE mean = 0.3767.

the origin or the destination is outside the planning area. A trip whose origin and destination are both outside the planning area would be a through trip. The external productions are the actual traffic volumes at stations on the cordon of the planning area. External attractions were developed based on interviews conducted at each station that identified origins and destinations inside the planning area.

Trip Distribution

The trip distribution model technique used in the Fayetteville urban area transportation study was the gravity model. The basic gravity model expression relates trip interchanges between two zones in terms of the total trips produced in the zone of production, the total trips destined to the zone of attraction, and measures of the spatial separation of the two zones. Spatial separation relates primarily to travel time between zones.

Traffic Assignment

The origin-destination modeled trips were assigned to the Fayetteville street network. The assignment computer program, adopted from the FHWA assignment program, used the all-or-nothing assignment concept; i.e., all trips from one point to another were assigned to one path based on the shortest distance in time between the two points. All turns in the street system were given turn penalties varying from 0.15 to 0.35 min depending on location, and each link (street section) in the network was assigned a travel time based on the operating speed of that street section.

Greensboro-High Point-Gastonia Composite Models

The origin-destination study data banks in the Greensboro, High Point, and Gastonia urban areas were merged to provide a larger sample. The merged data provided survey data for an urban population range of 50,000 to 250,000 people. This larger sample from varying population sizes provided additional explanation of the variations in trip-making patterns. The synthesized productions for the Fayetteville urban area were developed from this merged sample. The synthesized attractions were based on linear regression models developed in Greensboro.

Generation of Synthesized Data

Synthesized Productions and Attractions

Internal Trips

The synthesized zonal productions for Fayetteville were developed by cross-classification analysis of the composite origin-destination data files from Greensboro, High Point, and Gastonia. In cross-classification analysis the change in one variable can be measured when the changes in two or more other variables are accounted for. In this sense cross-classification analysis is similar to the more widely used multiple regression technique; however, cross-classification analysis does not rely on an assumed distribution of the underlying data and is sometimes referred to as the distribution-free technique. Essentially, n independent variables are stratified into two or more appropriate groups to create an n-dimensional matrix. Observations on the dependent variable are allocated to the various cells of the matrix based on values of several independent variables and are then averaged.

The independent variables used in this research--household size (persons per household), income (income per household), and automobile availability (automobiles owned per household)--were used on a zonal average basis. The dependent variable was average automobile driver trips generated per household per day for each of the independent variable cross classifications. The cross-classification matrices were different for each of the four purposes. The matrices for each trip purpose are given in Tables 3 to 6.

Table 3. Automobile driver trip production rates: home-based work trips.

No. of Automobiles per Dwelling Unit	Mean Income ($)	Trips per Household per Day by No. of Persons per Dwelling Unit: 1	2	3	4	5	≥6
1	5,200	0.61	0.75	0.89	1.05	1.19	1.34
	13,500	1.04	1.18	1.32	1.48	1.61	1.77
	18,700	1.22	1.37	1.51	1.66	1.81	1.95
	26,000	1.42	1.54	1.70	1.84	1.98	2.14
	46,800	1.60	1.74	1.89	2.04	2.18	2.33
≥2	5,200	1.18	1.32	1.46	1.59	1.73	1.86
	13,500	2.03	2.17	2.29	2.44	2.58	2.71
	18,500	2.33	2.46	2.60	2.73	2.87	3.01
	26,000	2.54	2.68	2.81	2.94	3.09	3.22
	46,800	2.25	2.39	2.52	2.67	2.80	2.93

Table 4. Automobile driver trip production rates: non-home-based trips.

No. of Automobiles per Dwelling Unit	Mean Income ($)	Trips per Household per Day by No. of Persons per Dwelling Unit: 1	2	3	4	5	≥6
1	5,200	1.07	1.10	1.12	1.15	1.18	1.22
	13,500	2.01	2.06	2.07	2.11	2.87	2.16
	18,500	2.40	2.43	2.47	2.49	2.51	2.55
	26,000	2.77	2.79	2.83	2.85	2.89	2.91
	46,800	3.04	3.06	3.10	3.12	3.15	3.17
≥2	5,200	0.78	1.12	1.46	1.81	2.15	2.49
	13,800	1.43	1.77	2.11	2.45	2.79	3.14
	18,500	1.83	2.16	2.51	2.86	3.19	3.53
	26,000	2.35	2.70	3.05	3.38	3.73	4.05
	46,800	3.80	4.13	4.46	4.81	5.15	5.43

Table 5. Automobile driver trip production rates: other home-based trips.

No. of Automobiles per Dwelling Unit	Mean Income ($)	Trips per Household per Day by No. of Persons per Dwelling Unit					
		1	2	3	4	5	≥6
1	5,200	1.16	1.43	1.69	1.96	2.23	2.50
	13,500	2.02	2.29	2.56	2.82	3.10	3.36
	18,500	2.40	2.68	2.94	3.21	3.47	3.75
	26,000	2.77	3.03	3.31	3.57	3.84	4.15
	46,800	3.08	3.35	3.61	3.78	4.15	4.42
≥2	5,200	0.98	1.67	2.35	3.03	3.72	4.40
	13,500	1.44	2.00	2.81	3.57	4.18	4.86
	18,500	1.72	2.40	3.09	3.78	4.54	5.14
	26,000	2.10	2.89	3.47	4.16	4.85	5.45
	46,800	3.16	3.84	4.23	5.19	5.89	6.32

Table 6. Automobile driver trip production rates: home-based shopping trips.

No. of Automobiles per Dwelling Unit	Mean Income ($)	Trips per Household per Day by No. of Persons per Dwelling Unit					
		1	2	3	4	5	≥6
1	5,200	0.45	0.56	0.67	0.78	0.89	1.01
	13,500	0.74	0.86	0.96	1.08	1.20	1.30
	18,500	0.86	0.97	1.08	1.20	1.31	1.42
	26,000	0.96	1.08	1.19	1.30	1.41	1.52
	46,800	1.00	1.09	1.21	1.32	1.42	1.54
≥2	5,200	0.58	0.78	0.98	1.19	1.38	1.58
	13,500	0.92	1.11	1.31	1.50	1.71	1.89
	18,500	1.04	1.23	1.43	1.62	1.83	2.02
	26,000	1.12	1.31	1.52	1.71	1.91	2.10
	46,800	1.14	1.34	1.53	1.74	1.93	2.13

The independent variable data were readily available from the Fayetteville Planning Department on a census-tract level, and it required only a small amount of subdividing to get the data to the zonal level. After the independent variables were adjusted to the zonal level, the next step was to determine the number of dwelling units per zone. The zonal productions for the planning area were then derived by using the FHWA X-Solve computer program.

The X-Solve computer program used the previously developed cross-classification matrices. By using the zonal socioeconomic data (independent variables), the two sets of data were matched and trip generation rates were developed. After the average trip generation rate per household was interpolated for a given zone, this rate was then multiplied by the number of dwelling units in that zone and the product of this calculation was zonal trip productions. The zonal productions were then derived for all four trip purposes: home-based work, home-based other, home-based shopping, and non-home-based.

The trip-attraction-factor equations were borrowed from the Greensboro study (2). The Greensboro equations were determined by using a stepwise multiple linear regression analysis of several employment variables. The regression equations were of the following general form:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 \quad (2)$$

where

Y = trips attracted to the zone,
X_1 = manufacturing and industrial employment,
X_2 = wholesale and retail employment,
X_3 = highway retail employment,
X_4 = finance and government employment,
X_5 = service employment,
X_6 = dwelling units,
a = constant, and
b_i = regression coefficient for each X_i.

Work trips are by definition these trips made to the location of a person's place of employment and to locations that must be visited in the performance of a normal day's work. Work trips, then, are attracted to places of employment. Some work trips, although fewer of them, are also destined to residential and other zones. The following equation describes home-based-work-trip attractions:

$$Y = 17.55 + 0.915X_1 + 0.748X_2 + 3.515X_3 + 1.176X_4 + 0.992X_5 \qquad R = 0.95 \quad (3)$$

Shopping trips were defined as those trips made to do some shopping regardless of whether or not a purchase was made. Trips made for repairs and personal services were also recorded as shopping trips. The variables intuitively associated with shopping trips are retail employment and some categories of service employment. The regression analysis for shopping trips used all types of employment. Some of the zones in the central business district (CBD) and shopping centers were aggregated to a limited amount because they were so small that true trip attractions could not be obtained for them. Aggregation significantly reduced the standard error and increased the multiple correlation coefficient. The following equation describes home-based shopping-trip attractions:

$$Y = -3.004 + 1.655X_2 + 4.082X_3 + 0.456X_5 \qquad R = 0.94 \quad (4)$$

Home-based other trips are trips that have one end at the home of the person making the trip (the trip production end) and the other (the attraction end) at a place that serves one of the following purposes: personal business, medical or dental, social or recreational, school, change of travel mode, eating, or serving a passenger. Some of the zones for this equation were aggregated because of their homogeneous characteristics, which made it difficult to determine which zone was the actual attraction:

$$Y = -14.639 + 0.181X_1 + 1.439X_2 + 5.598X_3 + 0.766X_4 + 1.869X_5 + 1.054X_6 \quad R = 0.96 \tag{5}$$

Non-home-based trips are, as the name implies, those trips in which neither the origin nor the destination is at the home of the person making the trip. The origin is the production end, and the destination is the attraction end. The CBD zones and major traffic generators such as large shopping centers created a problem of distinguishing which zone was attracting how many trips. For this reason these adjacent areas were grouped, and this small aggregation did reduce the standard error. Non-home-based trip attractions are described by the following equation:

$$Y = -14.639 + 0.181X_1 + 1.439X_2 + 5.598X_3 + 0.647X_4 + 1.207X_5 + 0.687X_6 \quad R = 0.97 \tag{6}$$

External-Internal Trips

The numbers of external-internal trip makers interviewed during the external-cordon traffic survey were totaled at each entry station. These totals represent the external trip productions. The attraction factors for external trips were developed by regression analysis. The following equation describes external-internal trip attractions:

$$Y = 29.03 + 0.436X_1 + 0.712X_2 + 1.266X_3 + 0.514X_4 + 0.863X_5 \quad R = 0.93 \tag{7}$$

Truck and Taxi Trips

There were only 4,392 taxi trips per day, which was insufficient for development of a separate equation. Taxi trips were therefore considered with nonpersonal truck trips (personal truck trips, mostly those of panel and pickup trucks, were included in the internal survey). The following equation describes truck and taxi trip productions and attractions:

$$Y = 8.78 + 0.051X_1 + 0.185X_2 + 0.843X_3 + 0.204X_4 + 0.164X_5 + 0.200X_6 \quad R = 0.89 \tag{8}$$

Trip Distribution

The trip distribution model technique used in the Fayetteville urban-area transportation study was the gravity model. The basic gravity model expression relates trip interchanges between two zones in terms of the total trips produced in the zone of production, the total trips destined to the zone of attraction, and measures of the spatial separation of the two zones. Spatial separation relates primarily to travel time between zones. The trip-length-frequency curves were developed from the origin-destination survey and are shown in Figure 2 by purpose.

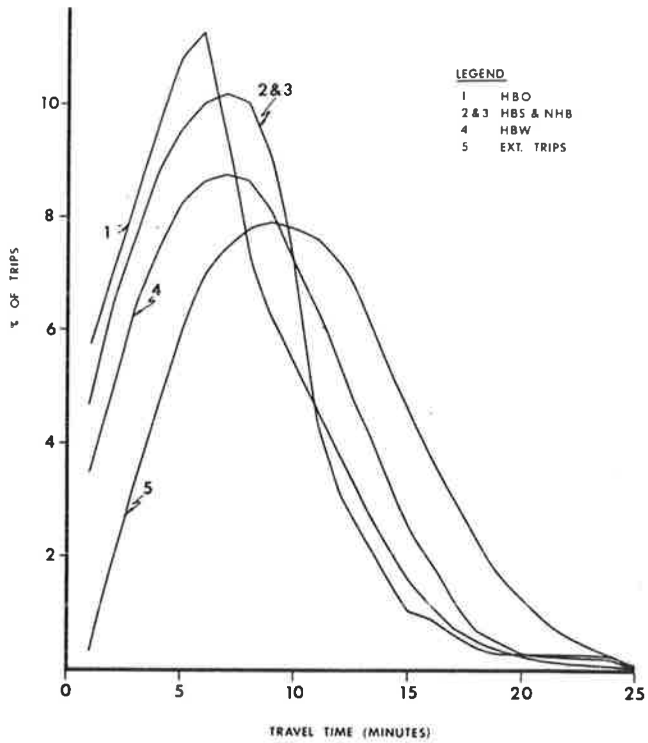
Traffic Assignment

Because the objective of the study was to determine how well the two models duplicated comprehensive traffic counts, both the origin and destination modeled trips and the synthesized modeled trips were assigned to the same street network and used the same traffic assignment procedure.

Analytic Technique

The two trip generation procedures were evaluated for their ability to duplicate the actual average daily traffic (ADT) volumes on the networks. The chi-square test is normally used to determine the level of accuracy of predicted travel as compared with actual travel. For the purpose and scope of this research, however, the chi-square test was considered too sensitive to be used. The percent root-mean-square (RMS) error (deviation) of estimated trips from actual trips was considered a suitable index for the accuracy of the models. The RMS error is expressed by the following equation:

Figure 2. Trip-length-frequency curves.



$$\text{RMS error} = \sum_{1}^{n} \left[(f_o - f_e)^2 / n\right] \tag{9}$$

where

f_o = number of observed trips or the actual trips,
f_e = number of trips estimated or expected, and
n = number of links for which comparisons are made.

The RMS deviation is similar to the standard deviation of a group of values around their mean and is associated with a two-thirds confidence interval. The percentage RMS error can be obtained by dividing the RMS error by the midpoint of the range of ADT being compared.

RESULTS

The two trip generation procedures were evaluated for their ability to duplicate comprehensive traffic volumes on the Fayetteville urban-area street system. Two techniques for evaluating the accuracy of these models were used: screen-line comparisons and street volume comparisons.

Screen-Line Comparisons

Screen lines are one of the most widely used comparisons in calibrating and evaluating traffic models. In this study, four screen lines were used. The assigned volumes for each of the trip generation procedures were compared with comprehensive traffic counts on each screen line. The results of these comparisons are given in Table 7.

Table 7. Summary of screen-line comparisons.

	Crossing Volume			Percentage Crossing	
Screen Line	Traffic Counts	Origin-Destination Model	Synthesized Model	Origin-Destination Model	Synthesized Model
A	151,440	154,200	147,600	101.8	97.5
B	47,900	51,800	47,800	108.1	99.8
C	127,100	129,700	126,600	102.1	99.6
D	48,100	45,600	41,400	94.8	86.1

Screen lines A and C are the major screen lines and provide a better comparison with the comprehensive traffic counts.

Street Volume Comparisons

The second method evaluates how well the two trip generation techniques duplicated actual traffic volumes in the Fayetteville planning area. The traffic volumes were compared on 853 street sections. This represented nearly every section of the Fayetteville major street system.

The technique used in comparing the two traffic assignments was to calculate the percentage RMS error (deviation) of each assignment by street section. This system of evaluation provided a better understanding of how much error there was in each respective assignment. It also made it possible to evaluate the street system as a whole instead of having to subclassify the street section into volume classes.

On the origin-destination model assignment, the percentage RMS error was 34.02. The synthesized assignment had a percentage RMS error of 37.69 and a 0.7 percent difference in mean volumes. The resulting percentage RMS errors were so close that statistically the two procedures produced essentially the same results.

A factor that caused the errors to be high on some sections and forced the RMS error higher was the assignment technique used.

Trips can be loaded on the street network at only a few points within each zone. Except in a few instances, in reality the streets are loaded gradually throughout the zone. The traffic volumes on certain street sections can therefore be lower than they would normally be and volumes on street sections in which the network is loaded can be higher than they would normally be. These factors would have an equal effect on both techniques.

SUMMARY AND CONCLUSIONS

The study described in this paper was performed to test the transferability of trip generation models from one urban area to another. Traffic volumes in the urban area of Fayetteville, North Carolina, duplicated by using synthesized trip generation models (cross-classification models and linear regression models) were compared with traffic volumes determined from a home interview origin-destination traffic survey. The synthesized trip generation models used an external cordon traffic interview survey and internal socioeconomic and travel characteristics developed from an aggregate sample of internal origin-destination surveys of the cities of Greensboro, Gastonia, and High Point.

Four screen lines were compared as one method of evaluation. For two of these screen lines the synthesized trip generation models were more accurate in duplicating the actual screen-line volumes than the origin-destination models (trip rate analysis models and linear regression models based on a comprehensive origin-destination survey). The origin-destination models were slightly better than the synthesized models for the remaining two screen lines.

A comparison of the percentage RMS error in duplicating street volumes on all major street sections was used as a second form of evaluation. The synthesized models had a percentage RMS error of 37.69, and the origin-destination models had a percentage RMS error of 34.02. The resulting RMS errors were so close that statistically the two procedures produced essentially the same results.

It should be noted that the relatively high percentage errors could be reduced by further calibration of the network. In addition, the larger percentage errors were associated with the street segments that had low traffic volumes, which are less significant. The percentage RMS error for the higher-volume streets was approximately 10 percent as opposed to an overall percentage RMS error of approximately 35 percent for both distributions. These factors would have an equal effect on both techniques.

Therefore, it can be concluded that the synthesized models adequately duplicated traffic volumes in urban areas of similar size and thus that trip generation models are transferable from one urban area to another urban area of similar size.

It is recommended that existing data banks be used in the development and calibration of transferable trip generation models. Using existing data and models eliminates the need for future comprehensive internal origin-destination surveys. Hence, significant savings in time and money can be realized in the transportation planning process. By using borrowed models, transportation professionals can respond to policymakers' needs in a more timely fashion.

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