and relative size of the attraction subarea. In addition, stratification of separate work, shopping, and other trip purposes might warrant further study.

ACKNOWLEDGMENT

The model described in this paper was developed under our direction as part of the Montachusett, Massachusetts, TDP study conducted by Alan M. Voorhees and Associates.

REFERENCES

1. D. T. Hartgen and C. A. Keck. Forecasting Dial-a-Bus Ridership in Small Urban Areas. Planning and Research Bureau, New York State Department of Transportation, Preliminary Res. Rept. 60, April 1974.
2. D. T. Hartgen. Modal Split in Small Urban Areas. Planning and Research Bureau, New York State Department of Transportation, Preliminary Res. Rept. PRR-15, July 1969.
3. D. T. Hartgen, G. H. Tanner, and R. A. Martino. An Empirical Approach to Estimating Mode Split in Small Urban Areas. Planning and Research Bureau, New York State Department of Transportation, April 1971.
4. T. Hillegass. Transit Travel Estimation for Smaller Urbanized Areas. Planning Methodology and Technical Support Division, Urban Mass Transportation Administration, Sept. 1975.
5. Ridership Estimating for the Merrimac Valley Area Transit Study. Merrimac Valley Planning Commission, Lawrence-Haverhill, MA, Staff Paper 7, March 23, 1976.
6. Brockton Area Transit Study: Estimating Ridership for Alternatives. Old Colony Planning Council, Lowell, MA, Staff Rept. 4, May 1975.
7. Highway Capacity Manual. HRB, Special Rept. 87, 1965.

Simulation of Travel Patterns for Small Urban Areas

Jerry G. Pigman and Robert C. Deen, Bureau of Highways, Kentucky Department of Transportation, Lexington

A study conducted to simulate travel patterns in small urban areas is reported. The purpose of the study was to develop models that would simulate internal-external trips and external-external (through) trips. Regression analysis and cross classification of data were tested in an attempt to predict the number of internal-external trips and the percentage of through trips. Regression analysis was used in the development of a through-trip distribution model. Grouping data for analysis created some problems; however, trial-and-error evaluation enabled the selection of variables that produced reasonable results. The variables found to be most significant in the development of internal-external-trip models are population and employment. For through-trip models, the variables used are population, functional classification, average annual daily traffic at the external station, and percentage of trucks. In developing through-trip distribution models, the variables of significance are average annual daily traffic at the destination station, percentage of trucks at the destination station, percentage of through trips at the destination station, and ratio of destination average annual daily traffic to total average annual daily traffic at all stations (value squared). Overall, for ease of application and accuracy, the models developed appear to be adequate for planning purposes.

Agencies responsible for determining when and where to construct new urban highways and streets, or to improve existing ones, must consider many factors in the decision-making process. One such factor is the purpose and volume of the traffic that can be expected to use the facilities in the future. Estimates of future traffic patterns are made by various traffic simulation models, usually some mathematical expression with parameters and constants to simulate traffic flow. Alternative transportation systems can be evaluated in terms of costs and benefits by entering socioeconomic descriptors into a simulation model to determine traffic patterns and volumes.

Travel patterns within an urban area are divided into three categories:

1. External-external or through trips—trips that originate and terminate outside the area,
2. Internal-external trips—trips that originate inside the area and terminate outside the study area or vice versa, and
3. Internal-internal trips—trips that originate and terminate within the area.

Historically, travel data for these three types of trips have been obtained from origin-destination (O-D) surveys. The external O-D survey, in which drivers of vehicles are interviewed at the study area boundary, provides data for internal-external and external-external trips. Internal-internal trip data are generally obtained by using home-interview, truck, and taxi surveys. The collecting, coding, editing, processing, and summarizing of these data often represent a major portion of the time and cost of conducting a transportation study. However, a review of completed studies has indicated that there are many similarities in models developed for trip generation and trip distribution that involve internal-internal trips, and this makes it possible to synthesize internal-internal trips by modeling. Many similarities are also apparent in internal-external and external-external trips. Synthesis of the trips involves applying values from O-D studies to other urban areas that have similar population and socioeconomic characteristics.

The models discussed in this paper were developed for simulating internal-external and external-external trips by emphasizing previously tested procedures and by selecting variables that characterize small urban areas in Kentucky.

REVIEW OF THE LITERATURE

The differences between large and small urban areas are apparently significant enough to make it necessary to separate them in traffic modeling. Most planners categorize areas that have less than 50 000 population as small urban areas.

Initial work in North Carolina was directed toward simulating internal travel by using trip generation data either from a small sample of home interviews or from data obtained from another similar urban area. By 1970, a procedure for synthesizing internal travel had been perfected to the extent that its use had become standard operating procedure (1). In 1970 and 1971, Modlin (2), working with the North Carolina Department of Transportation, was successful in synthesizing internal, external, and through travel for small urban areas.

The estimating procedure for through trips has consisted of three models (3). The first dealt with estimating the percentage of through trips from each external station given the functional classification of the facility external to the cordon, the current average annual daily traffic (AADT), the percentage of the facility external to the cordon, the percentage of panel and pickup trucks, and the population of the urban area. The second was a composite model composed of distribution models for each functional classification, which produced a triangular through-trip table. A third model estimated the percentage of total external trips by vehicles garaged inside the cordon as a function of employment available in the urban area.

In another study (4), previously developed corridor growth-factor models for developing future estimates of internal traffic in small urban areas were tested and modified. Regression equations were developed to provide data that are usually obtained from external cordon surveys. Alternative procedures for providing external survey information, based on historical data, were also developed. The completed procedure provided traffic volumes within the accuracy necessary for planning major thoroughfares in small urban areas.

Most studies of trip generation undertaken in the 1960s relied heavily on regression analyses. But a recent study sponsored by the Federal Highway Administration indicates that a combination of cross-classification and rate analysis was a more efficient and straightforward procedure for forecasting trip generation (5). Some of the advantages of using combined cross-classification and rate analysis are that the procedure is easy to understand, uses the data efficiently, and is easy to update.

DEVELOPMENT OF MODELS

Transportation studies of 20 cities scattered throughout Kentucky that have populations ranging from 6000 to 50 000 were the primary source of data for the analyses. As is the case with most prediction models, the procedure followed was a trial-and-error process of selecting independent variables that were easy to predict, met the test of reasonableness, and produced statistically sound results. Model formulation was confined to regression analyses and cross-classification techniques.

Internal-External Model

Inspection of internal-external equations developed in urban-area transportation studies reveals the types and the combinations of independent variables that were used to predict internal-external trips. The dependent variable (internal-external trips) and independent variables (various planning and socioeconomic factors) were the best combination of variables to represent base-year conditions and to predict future trip generation. Internal-external trips were obtained from O-D surveys. Population and employment data were available from censuses, and projections of these variables were considered good predictors of conditions at some point in the future. The study areas were grouped according to population.

Regression Analysis

Data on dwelling units, population, various types of employment, and internal-external trip attractions by zone were collected, tabulated, keypunched, and coded for computer analyses. Linear regression was the first type of analysis performed to derive a prediction model. Several combinations of independent variables were tested by using available data from the 20 Kentucky cities. Each internal zone was considered to be a separate set of data so that a total of 816 sets of data were available. The data sets were reduced from 816 to 762 because some exhibited unusually large, or small, numbers of internal-external trips.

An attempt was made to perform a regression analysis by using the complete data. The result was an inaccurate and unresponsive prediction equation. A second regression analysis was performed by using the zones within each study area as a data set. These equations characterized individual areas well, but the equations were not applicable to predicting trips in other areas. It became apparent that the study areas should be combined into population groups. Regression analyses were performed in which five population groups were used. The resultant equations are given in Table 1. The

Table 1. Internal-external trip prediction models: regression analysis.

Number of Study Areas	Population Group	Equation
6	5 000- 9 999	$Y = 10.25 + 0.53P + 5.41C + 0.81E + 0.57I$
7	10 000-14 999	$Y = 123.45 + 0.15P + 2.73C + 3.20E + 0.80I$
2	15 000-19 999	$Y = -28.41 + 0.38P + 2.72C + 3.28E + 0.69K$
3	20 000-29 999	$Y = 1.78 + 0.30P + 1.87C + 1.64E + 0.53I$
2	30 000-49 999	$Y = 60.76 + 0.05P + 1.26C + 0.30E + 0.051I$

Table 2. Cross-classification prediction of internal-external trips per internal zone.

Total Employment	0-150 Population: Trips	0-150 Population: Data Entries per Cell	151-500 Population: Trips	151-500 Population: Data Entries per Cell	>500 Population: Trips	>500 Population: Data Entries per Cell
0-5	59	87	87	51	317	8
6-50	154	46	185	73	340	63
51-100	179	22	222	39	485	52
101-300	436	30	464	70	610	87
>300	945	42	1150	43	1309	49

Table 3. External-external trip models: cross classification.

Functional Classification	AADT	Trucks in AADT (%)	Through Trips (%)	Entries per Cell
Primary arterial		0-5	12	2
	0-2500	6-10	31	3
		>10	41	6
		0-5	39	2
	2501-5000	6-10	31	7
		>10	49	15
		0-5	24	2
	>5000	6-10	49	10
		>10	64	15
Minor arterial		0-5	16	17
	0-2500	6-10	20	30
		>10	15	8
		0-5	28	9
	2501-5000	6-10	20	8
		>10	36	18
		0-5	10	2
	>5000	6-10	32	4
		>10	40	5
Collector	All	All	25	11
Local	All	All	19	3

following notation is used in the equations:

Y = internal-external trips by zone,
P = population of internal zone,
C = commercial employment by zone,
E = public employment by zone, and
I = industrial employment by zone.

Cross-Classification Analysis

The second type of analysis used to obtain internal-external prediction models was cross classification of data. The independent variables used for this analysis were zone population, total employment by zone, and dwellings by zone. The first cross-classification matrices were developed by using large numbers of categories for each variable. It was found that the number of entries per cell was not sufficient to give significance to this high degree of stratification because only 816 zones constituted the data base. From regression analyses, it was found that dwellings and population exhibited characteristics of collinearity; therefore, one or the other had to be dropped from the regression equations. Since both variables relied on the same characteristics of the urban area for prediction purposes, dwellings were omitted from the cross-classification analysis.

The resulting model, in its final form, is given in Table 2. Total employment by zone and population by zone are stratified into five and three groups, respectively. Because of the unusual nature of the attractors (businesses and institutions) previously mentioned, only 762 of the 816 internal zones were used for the final cross-classification analysis. The number of entries per cell in the matrix is also given in Table 2. A report on trip generation analysis by the Federal Highway Administration (5) suggests that at least 25 observations be accumulated for each cell. Only 2 of the 15 cells had fewer than 25 observations.

External-External Model

Percentage Through Trips

Regression Analysis

A North Carolina study (3) was used as a guide in testing a model with several independent variables to evaluate the percentage of through trips in the AADT at external stations. The independent variables in the regression analysis were AADT at the external station, percentage of trucks, population, functional classification of the highway at the external station, and employment. The same areas used in developing models to predict the percentage of through trips were used in developing internal-external trip models. There were 20 urban areas and a total of 177 external stations.

Of the 177 external stations, four functional classifications were represented. There were 61 external stations on primary arterials, 102 on minor arterials, 11 on collectors, and 3 on local routes. In the North Carolina study (3), functional classification was used as a dummy variable. The method of dummy variables involves coding the data in such a manner that only selected classifications would be entered into the regression equation; others would be omitted. Functional classification, however, yielded no improvement in the statistical values for the equation. Functional classifications were also considered in an equation for each class, but this also proved unsuccessful. Employment data did not significantly improve the predictive ability of the equation. Generally, it is best that prediction equations have relatively small constants; however, equations that were forced to have smaller constants were not acceptable because predictions were less accurate. After several attempts to segregate the data, the simplest equation that represented all functional classifications and gave the best predicting ability was developed (see Table 3):

$$Y = 0.003A + 1.49T - 0.0007P + 17.43 \quad (1)$$

where

Y = percentage of through trips of AADT at external station,
A = AADT at external station,
T = percentage of trucks of AADT at external station, and
P = population of urban area.

Cross-Classification Analysis

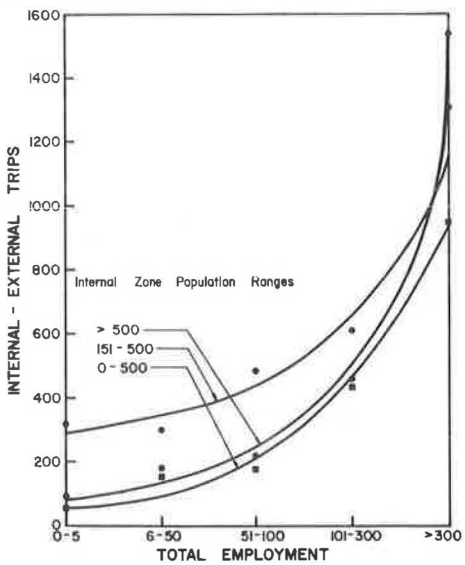
Recent work with cross-classification models has increased the confidence in this type of model for prediction purposes. Here, the first attempts to predict percentages of through trips by using cross classification were generally unsuccessful because too many variables and too much stratification were used. The population of the study area, the functional classification of the route at the external station, the AADT of the route at the external station, and the percentage of trucks in the AADT were the variables first considered. Area population was dropped first because too many blanks appeared in the cross-classification matrix. Functional classification, which was not a significant variable when it was entered into the regression equation, was found to be a practical means of segregating data for cross-classification analysis. Cross-classification models were developed for primary arterial and minor arterial functional classifications, but insufficient data were available to develop models for collector and local routes. The average percentage of through trips for the 11 collector routes and 3 local routes was considered to be representative of the 20 urban areas analyzed in this study.

After several attempts, the final cross-classification model used only three groups of AADT data and three groups of truck percentages for each AADT group. Therefore, there were nine cells in each of the models that represented primary arterials and minor arterials. These models and the average percentages of through

Table 4. External-external trip distribution models.

Functional Classification	Equation
Primary arterial	Y = 0.0001A + 0.11T + 0.22TT + 385.83R - 2.58
Minor arterial	Y = 0.0008A - 0.08T - 0.03TT + 228.14R + 6.20
Collector	Y = -0.000 01A + 0.11T + 0.05TT + 295.06R + 3.10
Local	Y = -0.01A - 0.03T + 0.83TT + 2704.73R + 1.95

Figure 1. Relation between internal-external trip attractions and total employment for various population ranges.



trips that represent collector and local routes are given in Table 3.

Distribution of External-External (Through) Trip Ends

The distribution of external-external (through) trip ends was accomplished by developing regression equations for each of the four functional classifications so that trip ends were distributed from each functional classification to all other functional classifications. External-external trip data were available for only 17 of the 20 urban areas used in the development of the other models in the study. A total of 1332 combinations of trip interchange data were available for use in the analyses.

External-external trip data had to be balanced and then doubled before being input into the distribution models. This was necessary to make the distribution of trips from one external station to all other stations equal to 100 percent. For example, if the balanced number of trips from external station A to external station B is 10 and the number from B to A is 10, then the total number of trips between the two external stations is 20. Handling the trip tables in this manner, the volumes at the external stations represent two-way traffic.

Of the 14 independent variables used in an attempt to predict the distribution of through trips, only 4 were considered significant enough to be included in the final model. To adequately represent two-way trips, it was felt that some function of both origin station and destination station should be included in the model. Results from the regression analysis, however, indicated that the variables that represented the origin station were relatively insignificant, and thus they were omitted from the equation. One variable—the ratio of the destination station AADT to the combined AADT at all external stations—did represent the origin station in an indirect way. The other three independent variables were the AADT, the percentage of trucks, and the percentage of through trips at the destination station. The models in their final form are given in Table 4. The following notation is used in the equations:

Y = percentage of trip ends from origin station distributed to each of the other functional classifications,
A = AADT at the destination station,
T = percentage of trucks in AADT at destination station,
TT = percentage of through trips in AADT at destination station, and
R = square of ratio of destination AADT to total AADT.

RESULTS

Internal-External Trip Models

Regression equations for internal-external trips are given in Table 1. In the equations, internal-external trip attractions are a function of the population of the internal zone, commercial employment, public employment, and industrial employment by zone. Table 2 summarizes the internal-external cross-classification model. In this model, internal-external trip attractions are a function of employment by zone and population by zone. Figure 1 was prepared as a graphical representation of internal-external trip attractions as a function of employment and population by internal zone. For all three population ranges, the number of internal-external trip attractions increases with increasing total employment.

Several statistical values were used to evaluate the accuracy and reliability of the internal-external trip models. For the regression analyses, the statistical values were the squared correlation coefficient, the standard error of estimate, the mean of the dependent variable, and the coefficient of variation. These values for each study and each group of studies are given in Table 5. As should be expected, the statistical results for the individual study areas were better than the results for the combination of studies.

Table 6 gives data on the predictive abilities of internal-external regression models and internal-external cross-classification models for each of the study areas based on the group equations. Included in the table are the number of zones used, actual and predicted trips, and root-mean-square errors for each of the 20 study areas. Root-mean-square errors were used as a means of comparing the predicted values calculated from the regression equations and the actual data obtained from O-D surveys. Two-thirds of the time, the predicted values will deviate from the observed values by an amount no greater than the root-mean-square error.

It is obvious that considerably better predictions were achieved by using the model developed from regression analysis than by using the model developed by the cross-classification analysis. As the data given in Table 6 show, the root-mean-square errors were significantly less for the regression model in all but one (Berea) of the 20 studies in which combined equations were used to generate predictions. Results also indicated that, when the study areas were grouped by population, greater accuracy was achieved by using the regression model. The large root-mean-square errors associated with some of the predictions can be explained in some cases by the unusually large or unique producers and attractors of trips. For example, the Murray area was examined from the standpoint of eliminating unique zones to see how the error of prediction was affected (6). Three zones that had employment three times greater than the average were discarded. The change in the root-mean-square error was from 346 to 249 for the regression model and from 693 to 238 for the cross-classification model. This indicated that the decision to discard some of the zones was very critical to the outcome of the prediction model. If some zones were discarded in the development of the general prediction model, it would be necessary to estimate the internal-external trip attractions by some other means. The most valid estimates are based on data from past studies that involve similar trip producers and attractors.

External-External Trip Models for Percentage of Through Trips

As Table 3 indicates, the regression equation developed

Table 5. Statistical comparison for each study area: internal-external regression equations.

Study Area	Study Year Population	Number of Internal-External Zones	R	Standard Error	Mean of Dependent Variable	Coefficient of Variation
Franklin	7 898	28	0.91	195	370	53
Cynthiana	6 700	20	0.98	138	563	25
Hazard	6 145	15	0.97	243	906	27
Mount Sterling	7 695	19	0.90	293	771	38
Nicholasville	7 464	24	0.95	234	646	36
Berea	9 210	24	0.81	120	331	36
Combined group		130	0.81	353	564	63
Murray	14 713	20	0.95	240	970	25
Glasgow	12 979	32	0.96	190	473	40
Somerset	14 031	20	0.87	383	1188	32
Elizabethtown	12 300	45	0.94	195	488	40
Danville	12 755	30	0.86	472	706	67
Corbin	11 430	31	0.95	135	426	32
Mayfield	13 436	25	0.90	289	1016	28
Combined group		203	0.79	404	690	59
Madisonville	18 224	48	0.96	147	411	36
Winchester	16 205	30	0.95	179	627	29
Combined group		78	0.94	171	494	35
Henderson	24 965	77	0.70	153	289	53
Hopkinsville	26 647	74	0.84	93	224	42
Richmond	23 477	31	0.87	356	793	45
Combined group		182	0.78	229	348	66
Paducah	50 000	95	0.58	133	212	63
Bowling Green	36 553	74	0.79	153	309	50
Combined group		169	0.71	143	255	56

Table 6. Internal-external trip predictions: comparison of regression analysis and cross classification.

Study Area	Internal-External Zones Used in Model	Actual Internal-External Average Trips per Zone	Cross-Classification Prediction (average trips per zone)	Cross-Classification Root-Mean-Square Error	Regression Prediction (average trips per zone)	Regression Root-Mean-Square Error
Franklin	28	370	311	459	418	203
Cynthiana	20	563	507	678	588	228
Hazard	15	849	533	809	990	280
Mount Sterling	19	771	449	684	641	298
Nicholasville	24	645	271	777	397	555
Berea	24	331	369	274	532	316
Combined group	130	564	488	621	563	339
Murray	20	970	652	693	910	347
Glasgow	32	472	481	640	536	330
Somerset	20	1187	704	882	900	459
Elizabethtown	45	488	395	554	534	254
Danville	30	706	543	959	950	686
Corbin	31	406	371	292	414	188
Mayfield	25	1016	677	564	840	367
Combined group	203	687	520	670	689	386
Madisonville	48	411	476	626	445	156
Winchester	30	627	533	551	580	186
Combined group	78	494	498	598	498	168
Henderson	77	289	418	281	298	177
Hopkinsville	74	224	421	437	298	147
Richmond	31	793	589	673	597	413
Combined group	182	348	458	439	349	226
Paducah	95	213	450	329	212	136
Bowling Green	74	309	585	435	285	171
Combined group	169	255	509	380	244	153

to predict the percentage of external-external trips was a function of AADT at the external station, the percentage of trucks, and population. The statistical accuracy of this equation was reasonable: The standard error was 15.53, the multiple correlation coefficient (R^2) was 0.53, and the coefficient of variation was 49.

Table 3 gives the final cross-classification model used to predict the percentage of external-external trips at an external station. This model was also a function of AADT at the external station and the percentage of trucks in the AADT at the external station, but the matrix did not include population. Functional classification was another means of segregating the data for the cross-classification analysis.

A comparison of the predictive abilities of external-external trip models is given in Table 7. Included in the table are the number of external stations used, the actual and predicted trips, and the root-mean-square errors for each of the 20 urban areas. The accuracy of the two models was approximately equal, but the number of entries per cell in the cross-classification matrix was so small that the reliability of the results must be questioned.

External-External Trip Distribution Models

As a result of exhaustive regression analyses, equations for each of the four functional classifications were developed (Table 4). Each of the equations was a function of AADT at the destination station, the percentage of trucks and the percentage of through trips at the destination station, and the ratio of the AADT at the des-

Table 7. External-external trip predictions: comparison of regression analysis and cross classification.

Study Area	Number of Stations	Actual Percentage of Through Trips (average per station)	Cross-Classification Prediction (average percentage of trips per station)	Cross-Classification Root-Mean-Square Error	Regression Prediction (average percentage of trips per station)	Regression Root-Mean-Square Error
Franklin	6	25.3	23.5	8.5	33.3	11.6
Cynthiana	6	30.5	31.2	15.1	34.0	11.9
Hazard	4	17.7	37.0	25.8	41.5	24.8
Mount Sterling	7	42.3	29.4	18.0	39.6	13.9
Nicholasville	7	41.8	34.4	12.7	36.0	9.9
Berea	8	20.0	22.8	6.1	29.5	14.6
Murray	9	18.5	30.0	12.5	33.1	16.1
Glasgow	8	33.5	36.1	15.1	35.4	14.0
Somerset	9	43.1	27.2	19.2	20.3	26.4
Elizabethtown	12	49.3	35.6	24.0	37.6	26.3
Danville	8	28.1	34.9	11.5	31.6	7.7
Corbin	7	44.1	42.1	15.3	31.6	28.0
Mayfield	12	31.7	30.2	17.4	30.3	15.7
Madisonville	8	30.2	29.7	10.3	33.4	8.8
Winchester	11	34.0	26.9	17.5	22.4	24.4
Henderson	10	47.2	34.9	19.4	27.4	25.8
Hopkinsville	12	25.9	34.3	18.0	26.9	15.1
Richmond	7	28.0	30.8	13.4	23.1	8.7
Paducah	15	18.1	29.2	16.5	22.8	9.3
Bowling Green	11	23.3	31.0	18.2	19.0	14.4
All areas	177	31.7	31.6	16.7	29.4	17.8

Table 8. Statistical results for external-external trip distribution models.

Functional Classification	Total Observations (functional class at origin)	Mean of Dependent Variable	R^2	Standard Error	Coefficient of Variation
Primary arterial	478	11.60	0.54	12.85	111
Minor arterial	733	11.61	0.43	11.13	97
Collector	79	11.74	0.35	12.64	108
Local	42	7.03	0.63	7.93	113

Note: Regression equations given in Table 4.

Table 9. Independent input variables.

Model	Regression Equation	Cross Classification
Prediction of internal-external trips	Population of internal zone Commercial employment by zone Public employment by zone Industrial employment by zone	Population of internal zone Total employment by zone
Prediction of external-external trips	AADT at external station Percentage of trucks in AADT at external station Population of urban area	Functional classification at external station AADT at external station
Distribution of external-external trips	AADT at destination station Percentage of trucks in AADT at destination station Percentage of through trips in AADT at destination station Square of ratio of destination station AADT to combined AADT at all external stations	

tination station to the combined AADT at all external stations.

Statistical results that show the accuracy of the models are given in Table 8. Although some statistical measures appear to produce inaccurate predictions, it is generally assumed that reasonably high standard errors exist with these prediction models. Results from these four distribution models compare favorably with results obtained by others (2, 3). Overall, the models appear to be adequately reliable for planning purposes, especially in relation to ease of application and accuracy.

SUMMARY AND CONCLUSIONS

In this research, three prediction models were developed: a model to predict the number of internal-external trips, a model to predict the percentage of external-external trips, and a model to distribute external-external trips. Both regression analysis and cross-classification techniques were tested in the development of the first two models, but only regression analysis was used to predict the distribution of through trips. Segregation of data into groups suitable for analysis did create some problems, but a method of trial-and-error evaluation enabled selection of the best combination of variables. The independent variables required as input into the two internal-external models, the two external-external (through) models, and the through-trip distribution models are summarized in Table 9. These independent variables were selected from data that were readily available, easy to forecast, and easy to monitor.

Population was the most significant variable that affected the outcome of the internal-external trip regression model. As previously noted, there were five population groups. These were found to be the most distinctive means of separating the study areas for analysis. Many of the small urban areas in Kentucky were found to have travel patterns very similar to those of other towns of comparable population. Although it is not verified here, other studies have shown that geographical distribution has considerable influence on travel patterns, as does the proximity of the town to Interstate, parkway, or other major routes. The socioeconomic characteristics of small urban areas also play a significant role in determining travel patterns.

For predictions of internal-external trips, the regression equations given in Table 1 should be used. These equations are categorized into five groups according to population of the urban area, and predictions of internal-external trips by zone are functions of zonal population and employment. The cross-classification prediction presented in Table 2 may have useful application if considerable care is taken to identify unique producers and attractors of trips and if special procedures for handling these trips are developed.

For predictions of the percentage of external-external (through) trips, the regression equation presented in Table 3, which is representative of all cases, should be used. The model for cross classification is also presented in Table 3, but its utility is questionable because of the small number of entries in each cell in the matrix.

It was necessary to develop an external-external trip distribution model to implement results from development of a percentage-through-trip model. Results from the percentage-through-trip model can be input directly into one of the four distribution models presented in Table 4. This will enable the user to determine the percentage of through trips at a particular external station and then to distribute these trips to the other external stations within the study area. The final results will be an external-external triangular trip table.

Overall, the models developed in this study appear to be appropriate for planning purposes, especially in their ease of application and accuracy.

REFERENCES

1. Procedure for Synthesizing Internal Traffic Movements. North Carolina Department of Transportation, Raleigh, 1976.
2. S. Khasnabis and M. R. Poole. Synthesizing Travel Patterns for a Small Urban Area. Traffic Engineering, Aug. 1975.
3. D. G. Modlin, Jr. Synthesis of Through Trip Patterns in Small Urban Areas. Department of Civil Engineering, North Carolina State Univ., Raleigh, 1971.
4. A. D. Jones. A Simplified Procedure for Major Thoroughfare Planning in Small Urban Areas. Purdue Univ., West Lafayette, IN, and Indiana State Highway Commission, Indianapolis, Joint Highway Research Project Rept. 18, July 1972.
5. Trip Generation Analysis. Federal Highway Administration, U.S. Department of Transportation, Aug. 1975.
6. Mel Conner and Associates. Murray, Kentucky, Urban Area Transportation Study. Kentucky Department of Highways, Lexington, Sept. 1968.

Framework for Transferring Travel Characteristics of Small Urban Areas

Hani S. Mahmassani*, Massachusetts Institute of Technology, Cambridge
Oreste M. Bevilacqua*, De Leuw, Cather and Company, San Francisco
Kumares C. Sinha, School of Civil Engineering, Purdue University, West Lafayette, Indiana

It is felt that smaller urban areas (less than 250 000 population) can benefit significantly from the transportation studies that have already been conducted in other, similar urban areas. The results of a study of the spatial transferability of various urban travel characteristics are examined. Such characteristics for the small metropolitan areas of Indiana, as well as other selected midwestern communities, are compiled and critically analyzed and compared with each other and with other local and national characteristics and trends. Trip frequency (generation) is