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.

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Framework for Transferring Travel Characteristics of Small Urban Areas

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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

examined at three levels of aggregation: areawide, zonal, and household. A framework is then provided for the transferability of trip-generation parameters of concern to planners.

Initiating a continuing, comprehensive, and coordinated transportation planning process can represent a formidable task for small metropolitan areas as their population reaches 50 000. This process usually follows the pattern set by the larger metropolitan areas in the 1950s, with its high requirements in terms of data collection (by origin-destination survey), technical complexity, and financial resources. However, the problems faced by smaller areas are usually different in nature, in magnitude, and in context from those in larger areas. Moreover, the changing emphasis in urban transportation planning (1) from long-range, large-system planning to short-range improvements aimed at making better use of existing facilities, coupled with public concern over environmental and energy issues, has led to a reassessment of program priorities. As a consequence of this change in planning orientation, the development and application of "conventional", full-scale, comprehensive transportation studies is becoming less appropriate. It is therefore necessary to develop and implement simplified alternative planning approaches that can reduce the time and cost required by the transportation planning process, thus saving resources that can be redirected toward program implementation and the resolution of other issues.

One approach to simplifying the transportation planning process is to eliminate the need for a full-scale origin-destination (O-D) survey, which is by far the most costly, time-consuming, and time-delaying element of the conventional process. This can be achieved by reproducing the travel patterns in the urban area under study, based on the socioeconomic and physical characteristics of that area, and using parameters and relations developed and calibrated in other areas where comprehensive O-D surveys have been conducted. In such an approach—referred to as synthetic travel demand modeling—the information traditionally obtained from the O-D survey is fabricated or synthesized by using parameters "borrowed" from "similar" areas. Questions arise, however, as to which parameters and relations can be transferred and which areas can be used as a source of such parameters.

This paper addresses the above questions for parameters and models that characterize the trip-generation (frequency) aspect of trip making. It presents a critical appraisal of some of the suggested synthetic modeling techniques and develops a framework for transferring trip-frequency parameters for three levels of aggregation: areawide, zonal, and household. This theoretical framework is supported by empirical evidence derived from the comparison of parameters obtained from various study areas for each of the relevant levels of aggregation.

SCOPE OF THE STUDY

Urban areas in Indiana that have populations between 50 000 and 250 000 were studied. The following Indiana urban areas were examined: Anderson, Evansville, Fort Wayne, Lafayette, Muncie, South Bend, and Terre Haute. The general characteristics of these areas are given in Table 1. The purpose of the study was to make more efficient use of the information made available by the full-scale transportation studies conducted in these areas. Its primary objective was to determine the extent to which this information could be used to develop "universal" travel parameters that could be applied in other, comparable urban areas and to provide the framework for such use. In other words, it would assess the transferability of parameters and models calibrated in certain areas to other areas and relate this transferability to characteristics of the urban areas (socioeconomic in the case of trip-frequency parameters).

Secondary objectives included the development of a data base that could be used for the following purposes:

1. Cross-checking of the output of the planning process in a given area by comparing key travel parameters with available information from other areas for the purpose of assessing its reasonableness (2), and
2. Input for quick-estimation ("quick-response") techniques that might be needed for rapid evaluation of policy alternatives (3).

Although this study focuses on urban areas in Indiana, it is anticipated that the results and procedures would be directly applicable to other midwestern communities that fall into the same size group. Because of the general nature of the results, their validity is by no means limited to the state or regional level.

DISTRIBUTION OF TRIPS BY PURPOSE

Variation Between Urban Areas

Transportation studies have usually classified internal trips by as many as seven purposes. In the interest of simplification, it is recommended that fewer trip purposes be used in the demand modeling process (4). For small urban areas, the following three trip purposes are usually adequate: home-based work (HBW), home-based other (HBO), and non-home-based (NHB).

Trip distribution by purpose (for internal vehicle trips only) for each of the study areas is given in Table 2. For those areas in which more than three purposes were used in the transportation study, the trips were combined accordingly into the three categories. Since the number of truck trips was relatively small compared with the total number of trips in these areas, truck trips were combined with non-home-based trips (standard procedure used in most small-area transportation studies).

Wilson and Kristoffersen (5) have shown that trip distribution by purpose is independent of city size for smaller and medium-sized cities. However, this does not necessarily imply that this distribution is identical for all cities. The hypothesis of the independence of the distribution of trips among purposes from the various factors that differentiate cities is tested in this section. A chi-square test was used for this purpose (6).

To use this test, the number of trips by purpose and by urban area can be arranged in a contingency table, with urban area as the row factor and purpose as the column factor. However, the actual frequencies (number of trips) obtained from the O-D survey (before expansion) should be used instead of the numbers or percentages given in Table 2 because the test statistic is sensitive to sample size. The hypothesis of independence was rejected with 99.5 percent confidence (χ^2_{data} = 5596 versus $\chi^2_{12,0.005}$ = 28.299). The results of this test, therefore, demonstrated that the distribution by purpose of internal vehicle trips was not the same for all small urban areas in Indiana.

Pairwise comparisons of each of the urban areas by use of chi-square tests also provided statistical evidence for the rejection of the hypothesis that trip distribution by purpose is identical in any two of the urban areas studied. However, from a practical standpoint (as opposed to a purely statistical one), and considering the

Table 1. General characteristics of study areas.

Characteristic	Anderson	Evansville	Fort Wayne	Lafayette	Muncie	South Bend	Terre Haute
Survey year	1971	1970	1961	1970	1971	1967	1971
Population	90 338	175 514	203 861	101 125	100 056	219 018	102 729
Occupied dwelling units	29 808	60 500	64 780	29 758	31 015	69 091	41 418
Automobiles per household							
Census[a]	1.30	1.26	1.36	1.27	1.30	1.30	1.18
Transportation study reports[b]	1.30	1.30	1.16	1.54	1.52	1.25	1.00
Persons per household	3.03	2.90	3.15	3.40	3.33	3.17	2.48

[a]From 1970 data for the SMSA.
[b]From reports for the study area (within the cordon area).

Table 2. Total trips by purpose.

	HBW		HBO		NHB[a]		Total	
Urban Area	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Anderson	47 105	16.2	145 958	50.3	67 139	33.5	290 202	100
Evansville	74 586	16.5	188 285	41.6	189 923	41.9	452 794	100
Fort Wayne	90 203	23.3	146 990	38.0	150 029	38.7	387 222	100
Lafayette	44 337	15.0	154 067	52.1	97 306	32.9	295 710	100
Muncie	38 591	13.4	159 017	55.2	90 641	31.4	288 249	100
South Bend	79 672	15.1	208 452	39.3	241 896	45.6	530 020	100
Terre Haute	36 745	15.7	121 836	52.1	75 130	32.2	233 711	100

[a]Including truck trips.

Table 3. Distribution of household trips by purpose for city of Evansville.

Number of Automobiles	HBW		HBO		NHB		Total	
Owned	Number	Percent	Number	Percent	Number	Percent	Number	Percent
0	6	22.2	15	55.6	6	22.2	27	100
1	2351	23.5	4996	49.9	2661	26.6	100 08	100
2	4000	25.2	6997	44.1	4872	30.7	158 69	100
≥3	1117	25.0	1974	44.1	1381	30.9	44 72	100

relatively large uncertainty accepted in transportation studies because of the very nature of the issues addressed (especially in the context of smaller urban areas, where the decision may concern the number of lanes of a certain facility), the percentage distributions of trips by purpose obtained for the study areas and given in Table 2 can be useful. The average (unweighted) distribution for these areas is as follows: HBW, 16.5; HBO, 46.9; and NHB, 36.6. These percentages can be used to develop gross estimations or as an initial assumption (to be adjusted later in the process) in a synthetic modeling effort (7).

Variation Within Urban Areas

In order to understand some of the factors behind the variation of the trip-purpose distribution between urban areas, this distribution was investigated within urban areas. Trips made by individual households are considered in this case. Separate trip-purpose distributions were developed for levels of household automobile ownership by using raw household O-D survey data collected in Evansville. The numbers and percentages of trips observed for each purpose and level (category) of automobile ownership are summarized in Table 3.

To test the hypothesis that the distribution by purpose of trips made by households is independent of the socioeconomic characteristics of households (as reflected in automobile-ownership status), a chi-square test similar to the one described earlier was used. Once again, test results led to the rejection of the independence hypothesis; i.e., it was found that the distribution of trips by purpose is related to the socioeconomic characteristics of the household.

No direct testing of whether the distribution of trips by purpose for each socioeconomic category is identical among urban areas was conducted. Later, however, this is done indirectly in relation to disaggregate household trip rates, where it is demonstrated that the average number of trips for each purpose made by individual households of a certain socioeconomic category does not differ significantly between urban areas. This conclusion, coupled with the conclusion that trip distribution by purpose is significantly different for each socioeconomic group within an urban area, appears to indicate that the variation of the overall (areawide) trip distribution by purpose between urban areas can, at least in part, be attributed to the variation of the socioeconomic mix (distribution of households among socioeconomic groups) between these areas.

The practical implications of the above are that areawide trip distributions by purpose should not be transferred indiscriminately between urban areas. Only if the socioeconomic mix is identical (which is not easy to prove in practice) can such a transfer be justified.

TRIP FREQUENCY (GENERATION)

Areawide Trip Rates

On an areawide basis, trip frequencies are most commonly expressed in terms of average number of trips per household and average number of trips per person, which are calculated from the overall number of trips and the overall number of households (or area population). These rates are useful in predicting total travel in an area or as a criterion for checking the reasonableness of survey results or model outputs. Vehicle trips per household as well as vehicle trips per person for the study areas are given in Table 4. These rates exhibit a fairly wide range of variation: 5.64-9.94 trips/household and 1.90-3.22 trips/person.

Table 4. Areawide vehicle trip rates.

Urban Area	HBW Per Household	HBW Per Capita	HBO Per Household	HBO Per Capita	NHB[a] Per Household	NHB[a] Per Capita	All Per Household	All Per Capita
Anderson	1.58	0.52	4.90	1.62	3.26	1.08	9.74	3.22
Evansville	1.23	0.42	3.11	1.07	3.14	1.08	7.48	2.57
Fort Wayne	1.39	0.44	2.27	0.72	2.32	0.74	5.98	1.90
Lafayette	1.49	0.44	5.18	1.52	3.27	0.96	9.94	2.92
Muncie	1.17	0.39	4.83	1.59	2.92	0.91	8.92	2.89
South Bend	1.15	0.36	3.02	0.95	3.50	1.11	7.67	2.42
Terre Haute	0.89	0.36	2.94	1.19	1.81	0.73	5.64	2.28

[a]Including truck trips.

Table 5. Cross classification of HBW vehicle trip production for Lafayette and Evansville.

		Trip Rate by Household Size				
City	Number of Automobiles Owned	One Member	Two Members	Three Members	Four Members	Five or More Members
Lafayette	0	0.004	0.004	0.091	0	0
	1	0.572	0.868	1.118	1.371	1.456
	2	0.867	1.870	2.266	2.280	2.231
	3+	-	2.0	2.704	2.232	2.888
Evansville	0	0.006	0.008	0	0.034	0
	1	0.829	0.910	1.179	1.375	1.345
	2	1.0	1.982	1.894	2.044	2.023
	3+	-	1.929	2.812	2.967	2.973

The factors behind this variation in aggregate areawide trip-frequency parameters were investigated by Chan in an effort to develop models for predicting areawide trip frequency (8). It was shown in that study that, for urban areas that had populations in the range of 50 000-800 000, only socioeconomic factors contributed to the differences in areawide trip-frequency parameters; urban form and structure were not differentiating factors in trip-frequency prediction. That same study found that average automobile ownership per dwelling unit (over the whole study area) showed the highest significant correlation with trip rates.

The regression equation developed by Chan for urban areas with populations of 50 000-800 000 is given below:

$$\text{Average number of person trips/household} = 1.262 + 6.591 \times (\text{average automobile ownership/household}) \quad R^2 = 0.412 \quad (1)$$

Testing this equation for the Indiana study areas showed that the equation does not lead to very accurate predictions. However, any areawide aggregate regression model is likely to suffer averaging biases inasmuch as average automobile ownership per household might not be a good representative of the distribution of automobile ownership for each household in the urban area.

To test whether the distribution of automobile ownership is independent of the urban area (i.e., similar for all areas), a chi-square test was again used. The statistical test in fact substantiated that the distribution of households by automobile ownership is not the same for all of these urban areas. Using this technique for testing the similarity between household automobile-ownership distributions of pairs of urban areas (2x4 contingency tables) shows that only two of the urban areas, Anderson and Muncie, have similar household distributions by automobile ownership. All of the others are different with respect to each other. This socioeconomic similarity between Muncie and Anderson is also reflected in the areawide trip rates. For Muncie and Anderson, respectively, vehicle trips per household equal 8.92 and 9.74 and person trips per household equal 12.95 and 13.18.

Automobile ownership was used in the above tests only as an indicator of socioeconomic characteristics. This does not mean that it is the only important factor in determining areawide travel frequency. The finer is the categorization of households by various socioeconomic characteristics in urban areas, the more accurate is the comparison between these areas and the more reliable are the results obtained by using borrowed parameters. This concept is described in greater detail in subsequent sections of this paper.

TRIP-GENERATION ANALYSIS AT THE ZONAL LEVEL

Most transportation studies use the zone as the basic geographic unit of analysis. Multiple-regression techniques are generally used to relate zonal trips (or average zonal trip rates) to zonal socioeconomic and land-use characteristics. This is a very familiar technique, and it will not be discussed here.

A feeling exists among many planners that zonal regression equations developed in a certain area could be transferred and used to model travel in a different area, especially in the case of small urban areas (5, 9, 10). Along the same line, equations based on pooled data from different cities have been developed and recommended for use in synthetic trip-generation analysis (9). This direct borrowing of zonal regression equations was tested for some of the urban areas included in this study by using the equations for internal vehicle trip production for each of the three purposes described earlier. This test demonstrated that aggregate models cannot be reliably transferred between different urban areas. To overcome the disadvantages of using aggregate models, it was suggested that regression equations with trips per household as the dependent variable be calibrated at the household level so that the household is considered as the basic unit of analysis (11). Trip-generation rates at the household level are discussed in the following section.

DISAGGREGATE HOUSEHOLD TRIP RATES

Two types of disaggregate household trip-generation models can be used: regression models calibrated at the household level or cross-classification (category analysis) models. Cross-classification models stratify households according to their socioeconomic character-

Table 6. Summary of t-test results: cell-by-cell comparison of Lafayette and Evansville trip rates.

Cell										
Automobiles	Members of Household	t[a]	HBW[b]	Are Means Different?	t[a]	HBO[b]	Are Means Different?	t[a]	NHB[b]	Are Means Different?
0	1	0.3152	1.960	No	3.5734	1.965	Yes	2.9024	1.965	Yes
0	2	0.4713	1.970	No	1.7257	1.960	No	1.2866	1.960	No
1	1	3.379	1.960	Yes	4.5151	1.960	Yes	0.4817	1.960	No
1	2	0.709	1.960	No	4.6519	1.960	Yes	3.5254	1.960	Yes
1	3	0.5929	1.960	No	0.648	1.960	No	0.5013	1.960	No
1	4	0.0331	1.967	No	1.939	1.967	No	2.3513	1.968	Yes
1	5	0.8887	1.970	No	0.1375	1.968	No	1.8203	1.970	No
2	2	1.0944	1.960	No	2.3101	1.960	Yes	0.3085	1.960	No
2	3	2.8879	1.967	Yes	1.1887	1.966	No	1.3155	1.965	No
2	4	1.9060	1.967	No	1.0002	1.967	No	1.9298	1.967	No
2	5	1.8103	1.965	No	1.8753	1.960	No	2.2254	1.960	Yes
3	3	0.2959	1.960	No	0.6842	1.99	No	1.0664	1.981	No
3	4	2.4935	1.974	Yes	1.9689	1.974	No	1.0842	1.979	No
3	5	0.2833	1.974	No	3.459	1.978	Yes	3.1343	1.980	Yes

[a] t-statistic computed from the data.
[b] $t_{d,l,0.025}$, t-statistic from standard distribution.

istics and provide estimates of trip rates for each of the household categories. Both types of models predict equally well over the full range of households and appear to be indistinguishable with respect to sample-size sensitivity (12).

Disaggregate household models have been shown to be superior to aggregate models in various respects, such as yielding better estimates of zonal totals and the mean trip rate (11). Disaggregate models are also more data efficient than aggregate models, requiring fewer data for their calibration (10, 13). Moreover, because of their behavioral nature it is claimed that they are stable temporally as well as spatially (10, 13-16).

The spatial stability of household trip rates and their consequent transferability between small urban areas are investigated in this section. Cross-classification models for Lafayette and Evansville have been developed for this purpose. Category analysis has been used instead of the household regression technique because of its ability to express nonlinear relations, its inherent distribution-free characteristic (statistical distribution of the trip rates within each cell need not be assumed), and its ease of understanding and application. The independent variables used to classify households are automobile ownership and number of household members, both of which have been shown to be the major determinants of household trip generation (17). For illustrative purposes, Table 5 gives the average HBW vehicle trip rates per household category for each of the two test areas.

To compare trip rates, the use of a test statistic comparable to the chi-square distribution has been suggested (14). This test provides an overall comparison of all trip rates from two separate trip tables. It is, however, very sensitive to differences in individual-cell mean pairs. In other words, if the rates for one of the cells are somewhat different for the two tables, the test might lead to the conclusion that the two tables are significantly different. Since only some cells might have different average trip rates (often because of bad data points or slight deviations in each of the cells), trip tables should be compared on a cell-by-cell basis. A t-test can be used for this purpose. The test statistic used in this situation involves the comparison of two means for two cells, each of which contains a sample from two independent random variables, where the respective sample sizes are unequal and greater than 30 and the respective population variances are unknown and not necessarily equal. The results of these tests, summarized in Table 6, lead to the conclusion that, overall, trip rates are not significantly different for the two areas for all three trip purposes. Only a few cells show significant differences. These might be caused by the inaccuracy of some of the observations, which might lead to erroneous rates.

This comparison strengthens the belief that disaggregate household models are transferable from one area to another, especially in the case of small urban areas, regardless of the socioeconomic differences between them. This conclusion is also consistent with the finding, demonstrated in an earlier section of the paper, that the distribution of trips by purpose is related to household characteristics. In spite of its simplicity and seeming lack of sophistication, cross classification is nevertheless the most appropriate technique for trip-generation analysis within the structure of the conventional urban transportation planning process.

CONCLUSIONS

It has been shown in this paper that overall trip distribution by purpose is not similar between urban areas. Within an urban area, trip distribution by purpose varies among socioeconomic groups.

In a parallel way, it has been shown that the variation of areawide trip-frequency rates among urban areas reflects the variation of the socioeconomic distribution of households between these areas. Areawide frequency parameters would therefore be transferable between urban areas only when these areas have a similar socioeconomic distribution of households.

To transfer trip-frequency relations (number of trips as a function of other variables), these relations should relate trip making to its basic socioeconomic determinants at the household, or disaggregate, level. Aggregate equations tend to mask the causal aspect of the relations, and care must be exercised in borrowing such equations. Empirical evidence to that effect has been presented: Zonal regression equations developed in the study areas led to erroneous results when they were used in areas other than the ones for which they were developed. However, unlike aggregate models, disaggregate household models demonstrate the highest potential as well as the strongest theoretical justification for being transferred between small urban areas. Therefore, it is felt that trip-generation rates computed in one urban area whose population is in the 50 000-250 000 range can be successfully applied to synthesize travel in another urban area of comparable size, if the trip rates are derived from household-level data.

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Land-Use-Allocation Model for Small and Medium-Sized Cities

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A residential land-use-allocation model most suitable for use in small and medium-sized cities is described. It can also be used in large metropolitan areas to serve as a check or backup method on the reasonableness of forecasts produced by more sophisticated models. The model makes use of Gompertz curves and the concept of holding capacity to allocate regional totals to planning areas. Residential development factors are then used to further distribute these planning-area totals to small areas such as census tracts or traffic zones. In an ex post facto test of this model in which the U-statistic was used as a measure of performance, the accuracy of the method was found to be excellent in comparison with that of sophisticated, computer-oriented urban development models. Use of the procedure will save money, time, and personnel, all of which are important considerations for planning organizations that work under a fixed budget.

Land-use-allocation models fuel the typical four-step sequential transportation models. The general land-use model used in this process takes areawide forecasts of several socioeconomic variables as control totals and uses some procedure to allocate them to small areas, usually traffic analysis zones. The allocation procedures currently used by transportation planning agencies range from traditional "manual" techniques to sophisticated urban development models such as the Projective Land-Use Model (PLUM). Many small and medium-sized cities do not have the expertise, time, or money to run these large-scale models but prefer to rely on simple, less expensive, and more transparent models. Such methods, however, have not been generally developed and validated.

This paper describes a simple method of land-use allocation for small areas, in which the concepts of holding capacity, Gompertz curves, rates of land consumption, and residential development factors are used.