Improving Truck Trip-Generation Techniques Through Trip-End Stratification

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Most existing urban truck-travel demand-forecasting techniques stratify truck trips into only two categories for modeling purposes—trips made by light trucks and trips made by heavy trucks. The rationale behind this stratification is that the trip-making characteristics of the two truck types are quite different and thus should be analyzed independently. The purpose of this research was to determine whether additional stratification of truck trips aids in improving the reliability of truck trip forecasts. Several additional stratifications were considered, including stratifications by vehicle type, trip purpose, and destination land use. Comparisons of truck trips stratified by vehicle type for three cities showed no improvement due to the stratifications. In general, the overall unstratified models were more statistically adequate, and the independent variables that were most significant in the stratified equations were comparable with those that appeared in the total truck model. Similar results were obtained when total internal truck trips were stratified according to trip purpose. The stratifications by trip purpose did show, however, that goods-related trips have a strong relationship with either commercial or retail employment, while service-type trips are most strongly related to measures of total employment. Results from the stratification by land use at destination, in which total truck trip ends were categorized as either industrial trips (those made to various types of industrial and manufacturing land uses) or consumer-related trips (those made to land uses associated with the resident population of a study area), showed some improvement over the more general overall models. In two of the three case studies, in fact, significant differences were noted between the stratified and unstratified results, in terms of both the types of independent variables employed and the statistical reliability of the regression equations themselves.

Most existing urban truck-travel demand-forecasting techniques stratify truck trips into only two categories for modeling purposes--trips made by light trucks (trucks that have only two axles and four tires and that usually weigh less than 10 000 gross lb) and trips made by heavy trucks (trucks that have more than four tires and that weigh more than 10 000 gross lb). Additional stratifications are sometimes made, for example, by subdividing heavy trucks into "medium" trucks (those that have no more than two axles and that weigh 10 000-20 000 lb) and "heavy" trucks (those that weigh more than 20 000 lb) (1). For the most part, however, the two-category breakdown is the one most frequently made.

The rationale behind the stratification by light and heavy vehicles is, of course, that the trip-making characteristics of the two types are quite different; therefore, they should be analyzed independently. Trip-length characteristics of the two truck types do, in fact, show considerable differences; this is indicated by the trip-length distribution and friction-factor values for the two truck types reported in previous research (2,3).

The purpose of this research was to determine whether additional stratification of truck trips aids in improving the reliability of truck trip forecasts. Several additional stratifications were considered: (a) additional stratifications by vehicle type (for example, panel and pickup trucks, other two-axle trucks, three-axle single-unit trucks, and all combination units), (b) stratification by trip purpose, and (c) stratification by land use at destination.

Testing for truck trip-generation modeling improvements through the additional truck trip stratifications involved the analysis of both external and internal truck-survey trip records from the origin-destination study files in each of several case-study cities. Zonal-level truck trip ends for each of the proposed trip stratifications by the various parameters listed above were sorted and accumulated, and regression equations were developed for the stratified data. Comparisons with the original unstratified regression equations (in terms of both the statistical adequacy of the regressions and the significant independent variables in the relationships) were made in order to reveal any improvements resulting from the stratifications.

The study begins by considering the effect of truck trip-end stratification in multiple-regression analysis by the three parameters listed above--truck type, trip purpose, and land use at destination. A proposed stratification of truck trips is then presented and the applications of the stratified regression relationships to truck-travel demand forecasting are discussed.

STRATIFICATION BY VEHICLE TYPE

The stratification of truck trips by vehicle size has been shown to be a logical approach to truck trip-generation analysis because of the unique trip-making characteristics of various types of trucks. Truck size is also important, however, in terms of facility design (for both geometric and pavement considerations), environmental impact analyses, fuel- and energy-consumption studies, and highway revenue forecasts from estimates of truck vehicle miles of travel.

The traditional stratification of truck trips into those made by light and heavy vehicles, however, when used to develop multiple-regression relationships to forecast truck trip ends, has generally yielded unsatisfactory results. Correlations usually have been low; standard errors have been quite high; and, in general, the equations have tended to be so complex and unwieldy as to make forecasting extremely difficult.

It was felt, therefore, that the investigation of additional truck trip stratifications based on vehcle size might result in improved and simplified truck trip-generation models. Accordingly, truck trip origin-destination data were obtained from three case-study cities--Gastonia, North Carolina; Flint, Michigan; and Saginaw, Michigan--and stratified multiple-regression relationships were developed by truck type and compared with the overall unstratified regression equations for each city. The results of the stratifications by vehicle type for each of the three cities are summarized below.

Gastonia

Two separate trip stratifications by vehicle type were developed. The first stratification broke down the total truck population into panel-and-pickup trucks versus other-than-panel-and-pickup trucks. The second stratification considered all single-rear-tire trucks separately from all other-than-single-rear-tire trucks. Results of the two stratifications for internal and external truck movements are given in Table 1.

It can be seen from Table 1 that the stratifica-

Table 1. Gastonia internal and external truck trip destinations by truck type.

Regression Equation	Overall F	R^2	Standard Error ÷ Mean	Mean ($\bar{Y}$)	Correlation Coefficient[a] r_{12}	r_{13}	r_{23}
Internal Destinations							
Panel and pickup = 41.6 + 2.35 (HE) + 0.10 (TE)	61.3	0.3622	1.0309	87.84	0.506	0.468	0.313
Other than panel and pickup = 34.6 + 0.76 (RE) + 0.23 (LIDU)	52.1	0.3252	1.1619	71.92	0.527	0.227	0.016
Single rear tire = 47.6 + 1.14 (RE) + 0.33 (TDU)	55.2	0.3384	1.0286	123.95	0.504	0.283	-0.016
Other than single rear tire = 22.0 + 0.30 (RE) + 0.71 (HE)	44.6	0.2924	1.3644	35.80	0.508	0.459	0.618
Total = 77.7 + 1.54 (RE) + 0.54 (LIDU)	59.6	0.3555	1.0163	159.75	0.536	0.269	0.016
External Destinations							
Panel and pickup = 12.21 + 0.14 (RE) + 0.02 (TE)	91.1	0.4577	0.8003	20.31	0.609	0.546	0.468
Other than panel and pickup = 4.28 + 0.19 (HE) + 0.01 (TE)	47.7	0.3066	1.1224	8.86	0.428	0.468	0.313
Single rear tire = 12.57 + 0.15 (RE) + 0.02 (TE)	95.5	0.4693	0.7946	20.97	0.622	0.545	0.468
Other than single rear tire = 4.05 + 0.16 (HE) + 0.01 (TE)	42.0	0.2802	1.1649	8.19	0.394	0.459	0.313
Total = 17.4 + 0.20 (RE) + 0.03 (TE)	91.7	0.4592	0.7960	29.16	0.601	0.558	0.468

Note: HE = highway employment; TE = total employment; RE = retail employment; LIDU = low-income dwelling units; TDU = total dwelling units.

[a] r_{12} = between dependent variable and first independent variable; r_{13} = between dependent variable and second independent variable; r_{23} = between independent variables.

tions by panel-and-pickup versus other-than-panel-and-pickup and single-rear-tire trucks versus other-than-single-rear-tire trucks did not improve the truck trip-generation results. In fact, both stratifications actually increased the standard error of the estimate as a proportion of the mean, and only one stratified equation--that for panel-and-pickup truck destinations--had even the slightest increase in the value of R^2. The value of overall F, significant at the 0.01 level for all equations, was increased in only one of the stratified equations--again that for the panel-and-pickup equation.

Only five independent variables appear in the five equations, indicating little underlying difference between the stratified trip types. Retail employment, for example, was the most significant independent variable in four of the equations. In general, the panel-and-pickup and single-rear-tire truck equations were more acceptable than the equations for the larger trucks. The equation for other-than-single-rear-tire trucks, in fact, may be difficult to interpret because of the existence of colinear variables (the correlation between the two independent variables is higher than the correlation of either of them with the dependent variable). The net effect of the stratification by truck type for internal truck destinations was that the regularity of small trucks was much more apparent than that of the larger, dual-tired single-unit and combination vehicles. Modeling of the movements of these heavier vehicles would thus seem much more risky.

Similar conclusions may be reached regarding the regression relationships for the external truck movements. Once again, significant regressions were achieved in all cases, but little improvement resulted from the stratifications. The value of R^2 was higher than that for the unstratified equation in only one instance, and standard errors as a proportion of the mean were actually increased in three of the four stratified equations. Only three independent variables were represented in the five equations; either retail or highway employment was the most significant variable, and total employment was the second variable to enter the equations in all cases.

An additional constraint placed on the stratification of the external truck movements was the fact that there were comparatively few destination trip ends for the larger trucks. As a result, the regression relationships for these movements are even more questionable.

Flint

Truck trip data for the Flint urbanized area allowed a total of three stratifications to be considered--single-unit vehicles with single tires versus other-than-single-unit vehicles with single tires, single-axle vehicles versus other-than-single-axle vehicles, and single-unit trucks versus combination (tractor-trailer) units.

An examination of the Flint results showed that the three straight truck equations (single-unit vehicles with single rear tires, single-axle trucks, and single-unit trucks) all contained the same independent variables (total employment and total automobiles) as the total truck equation. In addition, the single-unit equations all had approximately the same statistical adequacy (in terms of R^2 and percentage of standard error) as the overall equation, and there seemed to be no confounding effects due to colinearity among the variables.

Where all the Flint stratifications by vehicle type failed, however, was in their attempts to model the trip ends for heavier trucks. The equations for all three of these categories (other-than-single-unit vehicles with single tires, other-than-single-axle trucks, and combination units) were quite weak and had considerably lower values of R^2, high standard errors of the estimate, and quite low, although still significant, overall F values. The independent variables in the "other-than" categories, moreover, while significant from a statistical standpoint, sometimes did not seem logically correct. For example, while the use of commercial employment as an important predictor of trip ends for heavy trucks may make sense in the equation for other-than-single-unit vehicles with single tires, it is difficult to see the relationship of total dwelling units to trip ends for heavy trucks, as one of the regression equations indicated.

In summary, it can be said that no improvement was observed for either the internal or external truck trip-destination models in Flint when stratified by various combinations of vehicle type. Although one portion of the stratification always yielded results comparable to the overall, unstratified equation, the complementary equation was always much poorer; the overall result was to make the entire stratification no better, and often worse, than the original unstratified equation.

Saginaw

Stratifications identical to those used in Flint

Table 2. Gastonia internal truck trip destinations by trip purpose.

Regression Equation	Overall F	R^2	Standard Error ÷ Mean	Mean ($\bar{Y}$)	Correlation Coefficient[a] r_{12}	r_{13}	r_{23}
Goods = 50.1 + 1.10 (RE) + 0.33 (LIDU)	64.1	0.3726	1.0470	104.07	0.564	0.242	0.016
Service = 27.8 + 1.15 (HE) + 0.07 (TE)	39.8	0.2694	1.1904	55.68	0.395	0.443	0.313
Total = 77.7 + 1.54 (RE) + 0.54 (LIDU)	59.6	0.3555	1.0163	159.75	0.536	0.269	0.016

Note: RE = retail employment; LIDU = low-income dwelling units; HE = highway employment; TE = total employment.

[a] r_{12} = between dependent variable and first independent variable; r_{13} = between dependent variable and second independent variable; r_{23} = between independent variables.

were employed in the analysis of the Saginaw data. Thus, three stratifications were made and compared with the overall equation for truck trip destinations.

Results of the vehicle-type stratification for internal truck trips in Saginaw showed that, once again, although significant regressions were achieved, no improvement in the equations resulted from the stratifications. The minimal increases in the coefficient of multiple determination and the slightly lower values of the standard error of the estimate as a proportion of the mean for the single-unit categories in the first two stratifications were more than offset by complementary inverse changes in these values for the corresponding "other-than" equations. In addition, in only three of the six stratified equations did independent variables other than those in the unstratified equation enter.

Similar conclusions may be reached regarding the stratification of the Saginaw external truck trip destinations. In this case, none of the stratified equations contained independent variables other than those that appeared in the original unstratified equation. Values of R^2 and percentage of standard error, moreover, did not show overall improvement due to the stratifications, even though the individual single-unit equations were improved somewhat. In general, however, the stratifications by vehicle type once again were no better than the original unstratified equation.

STRATIFICATION BY TRIP PURPOSE

Stratification of vehicle trips by trip purpose has long been a practice in the modeling of passenger movements. Although the trip-purpose stratifications employed in passenger-travel demand forecasting are dictated primarily by the trip-distribution model requirements (4), decisions must be made at the trip-generation stage as to the number and type of trip-purpose stratifications to employ.

Considerations in the stratification of passenger trips by trip purpose include not only the number of trips in each category but also the trip-length distributions of each trip purpose and the ability to forecast future trips in each category separately (4). Thus, the total number of trip purposes may range from eight or more in large urban-area studies to as few as three (home-based work, home-based other, and non-home-based trips) in the smaller urban areas.

Transferring the above reasoning to an analysis of goods-movement vehicle trips indicated that some stratification of truck trips by trip purpose should be investigated. Although a number of stratifications by trip purpose are theoretically possible, it is necessary to limit the total number of purposes both because of the comparatively small number of truck movements taking place and also because of limitations on the number of trip-purpose categories traditionally collected in an origin-destination survey.

Truck trip data available for this research were thus grouped into two general trip-purpose categories--goods-related trips (trips whose primary purpose is the pickup or delivery of goods) and service-related trips (trips in which the vehicle is used in connection with some type of service function). Data from two of the case-study cities used in the truck-type analysis--Gastonia, North Carolina, and Flint, Michigan--were also available for use in stratification by trip purpose, although only for the internal truck survey.

Gastonia

Two stratification categories by trip purpose for the internal truck trip destinations in Gastonia were created. "Goods" movements consisted of trips coded to pick up goods, deliver goods, pick up and deliver goods, and garage address. "Service" truck destinations included the trip purposes of service call, vehicle repair, and personal business.

A comparison of the trip-purpose stratification for Gastonia with the overall unstratified equation is given in Table 2. Goods truck destinations, which made up about two-thirds of the total truck destinations, are seen to be best predicted by the same independent variables presented in the overall model. The coefficient of multiple determination for the goods model is somewhat higher than that for the overall equation; the standard error as a proportion of the mean, however, is higher for the stratified goods model.

The significant independent variables in the service model are highway employment (defined as employees in establishments that primarily serve highway users, such as motel, restaurant, and service-station employees) and total employment; neither of these variables appears in either the overall or the goods-related equation. The R^2 value for the service category, however, is quite low; the standard error as a proportion of the mean is somewhat higher than that in the other two equations; and the overall F value, though still significant, is considerably lower than those for either the total or the goods model. The stratification by trip purpose may be of some value, nevertheless, since it shows the relationship of goods-related trips to measures of retail employment and the importance of service functions, such as those related to highway service stations, as a predictor of service-related truck trips.

Flint

The internal truck trips in Flint were similarly grouped into two general trip-purpose categories. The goods movements included trips coded to pick up goods, deliver goods, pick up and deliver goods, and base of operations. The service category included trips coded to and from work, shopping, personal business, service and other work-connected trips, and vacation.

Results of the stratification by trip purpose for

Table 3. Internal truck trips by land use at destination.

Regression Equation	Overall F	R^2	Standard Error ÷ Mean	Mean ($\bar{Y}$)	Correlation Coefficient[a] r_{12}	r_{13}	r_{23}
Flint							
Industry-oriented = 37.6 + 0.20 (OE) + 0.13 (ME)	420.1	0.7292	1.5410	82.48	0.269	0.847	0.196
Consumer-oriented = 73.3 + 0.59 (CE) + 0.36 (TDU)	140.8	0.4745	0.6723	255.38	0.505	0.584	0.260
Total = 98.2 + 0.14 (TE) + 0.34 (TA)	146.4	0.4841	0.7450	337.86	0.568	0.339	−0.107
Saginaw							
Industry-oriented = 6.12 + 0.36 (TCE) + 0.09 (TE)	223.0	0.6380	1.7209	34.23	0.277	0.775	0.110
Consumer-oriented = 11.9 + 0.38 (TDU) + 0.37 (CE)	232.1	0.6472	0.7268	102.72	0.721	0.442	0.122
Total = 23.6 + 0.43 (TDU) + 0.12 (TE)	192.1	0.6029	0.8183	136.95	0.544	0.557	0.005
Columbus							
Industry-oriented = 16.2 + 0.29 (INE) + 0.18 (CTUE)	135.6	0.2625	2.1129	25.95	0.431	0.336	0.143
Consumer-oriented = 54.6 + 0.51 (INE) + 0.18 (CGE)	203.6	0.3482	1.1537	93.20	0.370	0.494	0.099
Total = 71.7 + 0.82 (INE) + 0.19 (CGE)	210.1	0.3554	1.1383	119.15	0.455	0.429	0.099

Note: OE = other employment; ME = manufacturing employment; CE = commercial employment; TDU = total dwelling units; TE = total employment; TA = total automobiles; TCE = transportation and communication employment; INE = industrial nonmanufacturing employment; CTUE = communication, transportation, and utility employment; CGE = commercial and government employment.

[a] r_{12} = between dependent variable and first independent variable; r_{13} = between dependent variable and second independent variable; r_{23} = between independent variables.

the internal Flint truck trips indicated that goods destinations are most highly related to commercial employment, while service-related destinations are most highly correlated with values of total employment and total automobiles, the same variables that appeared in the total truck equation. Neither stratified trip-purpose category, however, showed a significant improvement over the original total truck-destination equation. The service equation did show a somewhat higher value of R^2 and a higher overall F value but at the expense of a correspondingly higher value of the standard error as a proportion of the mean.

STRATIFICATION BY LAND USE AT DESTINATION

Detailed stratifications of urban goods movements have recently been proposed that relate to the land use classification at the destination end of a goods-movement trip. Fresko, Shunk, and Spielberg, for example, proposed a classification that consists of location-oriented goods trips that serve the basic employment facilities in an urban region versus resident-oriented goods movements that serve the needs of the resident population in the area (5). Similarly, Saunders categorizes goods movements as those attracted to either industrial land uses (industry, open space, transportation and utilities, and vacant) or nonindustrial or consumer-oriented land uses (commercial, public buildings, residential, and services) (6). Finally, Hutchinson proposes grouping all goods movements into two distinct classes--interindustry and household-based movements (7).

As a final truck trip-end stratification category, internal truck trip records from three case-study cities--Flint and Saginaw, Michigan, and Columbus, Ohio--were stratified into two categories according to the land use at the destination: industry-oriented truck trips and consumer-oriented truck trips.

Flint

For Flint, industrial trips consisted of those whose destination land use codes were manufacturing; transportation, communication, and utilities; wholesale trade; resource production and extraction; and undeveloped land and water areas. Consumer-oriented land uses included residential, retail trade, services, and cultural, recreational, and entertainment.

Results of the regression analyses for the truck data stratified by land use at destination are given in Table 3. The stratification shows that industrial destinations are best predicted by manufacturing and other employment variables. Consumer-oriented destinations, on the other hand, are most significantly related to what might be considered consumer-related variables, that is, measures of commercial employment and total dwelling units. Both stratified equations are quite different from the overall equation, which predicts total truck destinations from a combination of industrial-related (total employment) and consumer-related (total automobiles) variables.

In addition to the logical structure of the equations stratified by land use at destination, the statistical strength of the separate equations seems improved over that of the unstratified equation. The values of the overall F, for example, show that the industry-oriented equation is significant at a much higher level of confidence than either of the other equations. The consumer-oriented equation, on the other hand, has a lower F value than the overall equation and hence cannot be used with as much confidence. The two values are so close (146 versus 141), however, and the industrial-oriented F value is so high, that there can be little doubt that the stratification by land use at destination has, for the Flint data, resulted in some improvements over the traditional unstratified equation. All of the criteria for determining improvements have not been met, however, since the value of R^2 for the consumer-oriented equation is somewhat lower than that of the overall equation and since the standard error as a proportion of the mean for the industrial equation is quite a bit larger than that of the unstratified equation.

Saginaw

For Saginaw, the industrial category contained manufacturing, nonmanufacturing industry, commercial-wholesale, and other open-space land uses. The consumer-related category consisted of residential, commercial-retail, services, public and quasi-public buildings, and public and quasi-public open-space land uses.

Results of the land use stratification for

Saginaw are given in Table 3 along with the overall truck equation. It can be readily seen that this stratification has also resulted in some improvements over the overall equation, in terms of both the logical placement of the independent variables and the statistical strength of the stratified equations.

Industrial truck trips are strongly related to total employment (a large majority of which is industrial employment) and transportation and communication employment. Consumer-related truck trips, in contrast, are best predicted by total dwelling units and values of commercial employment. Finally, from a statistical standpoint, the values of the overall F for both of the stratified equations are significant at higher levels of confidence than that for the total truck equation. The standard error as a proportion of the mean for the industrial equation increased, however.

Columbus

In contrast to the results for the Flint and Saginaw land use stratifications, the stratification for Columbus (see Table 3) apparently has not resulted in improved, or even different, prediction equations. The independent variables in the industrial category--industrial nonmanufacturing employment and communication, transportation, and utility employment--are intuitively logical; industrial nonmanufacturing employment, however, also enters the equation used to predict consumer-related truck destinations.

Statistical results for the three equations for Columbus also indicate no improvement due to the stratification. The overall F value is higher for the total truck equation than for either of the stratified equations. Correspondingly, values of R^2 are naturally higher for the overall equation, and the standard errors are lower.

One possible explanation for the failure of the Columbus case study to indicate any improvement when stratified by land use at destination is the fact that the number of independent variables available for use in the study may have been too great. A total of 33 variables, including 9 employment and 16 floor-space or site-area variables, was available on a zonal basis. The effect of this fine level of detail may have been an inability of only two variables to account for significant amounts of variation in the stratified truck trip equations.

SUMMARY

The purpose of this research has been to investigate the effects of various stratifications of truck trip ends on the reliability of truck trip-generation equations. Three stratification criteria have been employed. Truck trip ends were first stratified by vehicle type, that is, single-axle trucks versus other-than-single-axle trucks, single-unit trucks versus combination units, and so forth. The regression equations for the stratified data were then compared with the corresponding regression model for the overall truck trips and any improvements, either in the adequacy of the independent variables entering the model or in the statistical validity of the model itself, were noted.

Comparisons of truck trips stratified by vehicle type for three case-study cities showed no improvements due to the stratifications. In general, the overall unstratified models were more statistically adequate, and the independent variables most significant in the stratified equations were comparable to those appearing in the total truck model.

Similar results were obtained when total internal truck trips were stratified according to trip purpose. In this case, two general categories were employed. Goods-related trips were those that had as their primary purpose the pickup or delivery of goods. Service-related trips had as their primary purpose the performance of a service function, such as vehicle repair or a service call. The stratification by trip purpose, which was investigated for data from two case-study cities, indicated no overall improvements when compared with the overall model. The stratifications by trip purpose did show, however, that goods-related trips have a strong relationship to either commercial or retail employment, while service-related trips are most strongly related to measures of total employment. These relationships perhaps could be improved further by deleting those trips made by small trucks for personal business reasons. An additional area of investigation could focus on the similarity of stratification results over several urban areas. This approach was not possible by using the limited data base available for this study. Such comparisons, moreover, would have to be made over areas that use identical truck trip-purpose categories.

The final criterion on which truck trip ends were stratified was related to the land use at the destination. By employing a stratification suggested by the literature on urban goods-movement forecasting, total truck trip ends were categorized as either industrial trips (those made to various types of industrial and manufacturing land uses) or consumer-related trips (those made to land uses associated with the resident population of a study area, such as residential, retail services, and cultural or recreational). These results for three case-study cities showed some indication of improved results compared with the overall models. In two of three case studies, in fact, significant differences were noted between the stratified and unstratified results, in terms of both the types of independent variables employed and the statistical reliability of the regression equations themselves. Improvements were not discernible in the third case, although this may be a result of a plethora of independent variables that do not individually contribute significantly to the model.

The relative success of the truck trip models stratified by land use at destination suggests that this approach might be an appropriate area of pursuit if any long-range modeling of urban truck trip generation is desired. Additional improvements in the adequacy of the stratified models may be realized by the elimination of zones that have zero observed trip values, as well as those that contain unique truck trip generators. This type of refinement, of course, requires that the analyst have an intimate knowledge of the area under investigation, which was not the case with this research.

Applications of this type of modeling of urban truck-travel demands, of course, are in the long-range planning area. Improved modeling of truck trips in this time frame may be most appropriate both for evaluating the consequences of alternative future land use plans and for facilitating the development of truck-route systems and other networkwide improvements.

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Stability Tests and Enhancements in Trip Distribution for Subarea and Corridor-Level Planning

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This paper describes the investigation of three key issues in the stability of trip distribution modeling as a means toward development of a more robust model that would form the linchpin of a state-of-the-art subarea planning tool, the thoroughfare analysis process. The three issues addressed are (a) stability across trip purpose, (b) stability under subarea focusing, and (c) stability through time and changing development patterns. A set of base models is initially calibrated in much the same way as in conventional fixed-zone modeling. These models are then subjected to a series of stability tests and, where necessary, model enhancements are introduced for further testing. Model refinements are introduced to obtain greater stability with respect to trip purpose and subarea focusing.

This paper describes research into the stability of trip distribution modeling; its goal is to develop a robust model for highly detailed planning at the subarea or corridor level, for both short-range and long-range purposes. The objective is to extend the state of the art in trip distribution to form the pivotal component of the thoroughfare analysis process (TAP), a planning package that is supported by a multilayered data base and that possesses an automatic subarea focusing feature. The structure of the TAP and its application in diagnostic analysis and evaluation at the subarea level are documented by Howe, Ryden, and Penny (1).

Subarea focusing is the means by which the data base for an urban or regional study area is disaggregated to finer detail within an area of interest and aggregated externally to permit cost-effective analysis in greater detail within the area of interest. Such a capability permits a more rigorous, systems approach to subarea planning, e.g., planning the principal and minor arterial network-supporting freeways, diagnostic analysis of transportation systems at the community level, evaluation of community-level transportation system management (TSM) and capital projects, and more detailed long-range analysis of alternative capital investments for corridor improvements.

The stability of trip distribution under focusing was initially addressed by Nihan and Miller (2). The initial calibration of a trip-distribution model for the TAP package was described by Howe and Gur (3). Extending previous work, the research described in this paper examines the stability of the TAP gravity-form distribution model from the following perspectives:

1. Stability across trip purpose--The research described in this paper led to a modified gravity formulation to attain greater stability under multipurpose modeling, which is essential to treatment of separate trip types in diagnostic analysis and evaluation.
2. Stability under subarea focusing--This issue is critical to subarea systems modeling in general. In this case, research pointed to incorporation of additional model parameters to compensate for variation in zone size.
3. Stability over time and changing development--Research indicated a marked degree of stability over a 13-year period of substantial growth and shifts in socioeconomic activity. This finding is important to the use of systems modeling for planning medium- and long-range capital alternatives.

As a starting point, trip distribution models were calibrated on base-year (1964) data that represent a uniform zone structure for a two-county study region, much as one would develop models for conventional planning on a fixed-zone structure. These base models were then subjected to a series of stability tests that addressed the above issues, and model enhancements were made as needed to attain improved robustness.

MODEL FORMULATION AND BASE CALIBRATION

Model Formulation

The trip-distribution model discussed in this paper