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CHOICE AND CAPTIVE MODAL-SPLIT MODELS

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This paper presents the findings of an investigation conducted to determine the desirability and feasibility of developing 2 sets of modal-split models—direct generation for captive transit riders and trip interchange for choice transit riders. The different characteristics of the dual transit trip-making population are defined by a set of hypothetical demand curves of transit services for both captive and choice riders. Whereas captive riders are inelastic with changes in the relative attractiveness of the transit and highway systems, choice riders are sensitive to changes in either highway or transit facilities. The standard method of treating these groups as one usually produces equations that are insensitive to system variables because the characteristics of the captives tend to dominate the models. Information gathered for the Miami, Florida, urban area was used to identify and quantify those factors affecting transit use into 2 sets of models.

●A CONSIDERABLE AMOUNT of effort has been expended during the past decade by transportation planners to solve the recurring question of what the division is likely to be between highway and transit use for a significantly different future transportation system. Most reviews of past research catalog all modal-split models into predistribution, post-distribution, and direct generation models. Stratification of transit rider data is usually by trip purpose. A common ailment of most of these efforts—especially in cities without existing rapid transit—is the lack of proof that relationships devised from existing conditions are meaningful when extrapolated into the future with major changes in the transit system.

In a recently completed examination of the state of the modal-split art, the CONSAD Research Corporation (1) concluded that "the present situation . . . finds none of the models producing forecasts which can be reliably used for decision-making purposes where major system changes are contemplated." A continuing problem is to develop models that are statistically sound but sufficiently sensitive to changes in the transportation system to reflect the effect of new transit modes.

Examination of transit patrons always reveals 1 consistent dichotomy regardless of the urban area: They subdivide into captive riders, who have no alternate means of transportation, and choice riders, who have an automobile available and could use it if they desired. In practically every city, captive riders outnumber choice riders by ratios ranging anywhere from 3:1 to 9:1. Captive riders as a group are inelastic with changes in the attractiveness of the transit system. If they are to make the trip at all, it must be made by transit. For this reason, attempts to develop models with system variables are futile insofar as this major group is concerned. The fact that they outnumber choice riders by such wide margins overrides any sensitivity that choice riders may have to changes in the transit system when the 2 groups are lumped together for multiple regression analysis.

On the other hand, choice riders in any urban area are using the transit system because it provides some distinct advantage (by their evaluation) over traveling by automobile. If anything is to be learned about responses of travelers to alterations in the

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relative attractiveness of the transit and highway networks, it must be learned from this group of transit users.

For these reasons and the fact that prior attempts at the development of typical trip interchange modal-split models in Metropolitan Dade County (Miami, Florida) produced results that were completely unresponsive to changes in the transportation system, it was decided to conduct the research reported here that examined the 2 basic groups of transit users in Miami—captive and choice—and that resulted in the development of separate modal-split techniques for each group.

Preliminary review of the characteristics of these groups and early regression analysis indicated not only that the groups should be divided but also that the model theory should be applied differently to each group. Tests were conducted that led to the development of direct generation models for captive riders and trip-interchange models for choice riders.

The rationale in selecting a direct-generation model for captive riders and a trip-interchange equation for choice riders can be explained by examination of a set of hypothetical demand curves (Fig. 1) for the 2 individual trip-maker populations. The graph relates the demand for transit service (expressed as the percentage of the trips made by transit) to a disutility index. This index quantifies the costs associated with each travel mode as measured by elements such as travel time, out-of-pocket expenses, and comfort and convenience factors. The index ranges from 0, which indicates almost ideally attractive transit service in relation to highways, to 1, which denotes equality in service, up to a maximum of 10, which represents an ideally attractive highway system (the opposite of the 0 condition).

For the captive trip-makers, the demand function is inelastic to the disutility index of the transportation system, and all trips are made by transit regardless of the value of the index. Of the 3 types of modal-split models (direct generation, trip end, and trip interchange), the direct generation procedure is the least sensitive to changes in the transportation system. Therefore, it was the most compatible with the captive transit demand curve. On the other hand, the choice trip-makers respond to changes in either highway or transit services as reflected in the disutility index. The elasticity of the transit demand function for choice riders can best be modeled by a trip-interchange type of formula because it is most responsive to specific system changes.

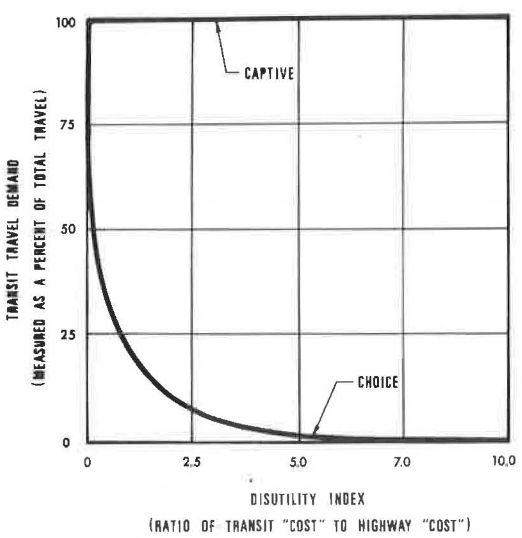

Figure 1. Hypothetical transit travel-demand curves for captive and choice riders.

CAPTIVE TRANSIT RIDER MODELS

As previously noted, the captive transit riders represent those members of the trip-maker population who have no automobile available for their trips and, therefore, have no choice in the selection of travel modes. If the trip is to be made, it must be made by transit. In view of this characteristic, the possibility of developing direct transit trip-generation models was examined. With this method, the number of captive transit trips produced and attracted in each zone is related to the demographic and economic characteristics of the individual zone. Six different trip categories were chosen to reflect the different characteristics of travel by trip purpose: home-based work, home-based shop, home-based social and recreational, home-based school, home-based miscellaneous, and non-home-based. These trip-purpose categories are the same as those developed by the Miami Urban Area Transportation Study (MUATS) for estimating

TABLE 1

INPUT VARIABLES FOR REGRESSION ANALYSIS—CAPTIVE TRANSIT TRIP-ESTIMATING EQUATIONS

Variable	Mnemonic	Variable	Mnemonic
Residential dwelling units	RESDU	Labor force	LABFOR
Hotel and motel units	HMUNIT	Eating, drinking and amusement	
Total dwelling units	TOTDU	recreation employment	ED + AR
Resident population	RESPOP	General merchandise employment	GMEMP
Tourist population	TOUPOP	Commercial employment	COMEMP
Total population	TOTPOP	Total employment	TOTEMP
Automobiles owned by residents	RESAUT	Junior high school enrollment	ENJRHS
Automobiles owned or rented		Senior high school enrollment	ENSRHS
by tourists	TOUAUT	Other enrollment	ENOTH
Total automobiles owned or		College enrollment	ENCOLL
rented	TOTAUT	Total home-based attractions	HBATTR

total person trips. In a sense, the captive transit estimating equations can be thought of as minimodels that forecast only a segment of the total person trips.

Because certain portions of the 550-zone study area are not currently served by transit, only 452 zones or cases were used in model calibration. Generally, the excluded zones are located at the periphery of the study area and are largely undeveloped. A total of 19 independent variables (Table 1) were correlated with each of the 12 dependent travel variables (trip productions and attractions for each of the 6 trip purpose categories) by using the BMD02R statistical program. Those independent variables exhibiting the highest degree of correlation were tested in combination with other explanatory variables. Selection of the final models (Table 2) was based on optimizing the dual criteria of explained variation (coefficient of correlation) and the inclusion of logical independent variables. A discussion of each of the models is presented in the following sections.

Home-Based Work Trips

The 2 independent variables that are included in the captive transit work trip production model pertain only to the resident population. The size of the resident labor force within each zone is directly related to the number of captive transit trips produced, whereas, as might be expected, automobile ownership exhibits a negative effect on transit use. The estimating model for captive transit work trip attractions also includes 2 variables—total employment and number of hotel and motel units. Both variables appear to be logical, and a reasonable degree of correlation was evidenced.

Home-Based Shop Trips

The independent variables included in the captive transit shopping trip production model reflect the dual character of trip-makers in the area—resident and tourist. The equation indicates that the number of residential households and hotel and motel units within each zone serves to define the total amount of shopping trips produced, whereas the automobile ownership variables limit the proportion of total demand allocated to the captive transit mode.

The model developed for captive transit shopping trip attractions includes 2 measures of commercial activity—general merchandise employment and commercial employment. The correlation coefficient for this equation is somewhat low, but it is acceptable for planning purposes.

TABLE 2

MODAL-SPLIT MODELS—CAPTIVE TRANSIT TRIP-GENERATION EQUATIONS

Trip Category	Equation	R
Production		
Home-based work	0.24119 LABFOR - 0.08835 RESAUT	0.8240
Home-based shop	0.07734 RESDU - 0.01484 RESAUT + 0.15936 HMUNIT - 1.01886 TOUAUT	0.8429
Home-based social-recreational	0.05104 RESDU - 0.01324 RESAUT + 0.11107 HMUNIT - 0.60464 TOUAUT	0.7386
Home-based school	0.04479 RESPOP	0.8106
Home-based miscellaneous	0.06504 RESDU - 0.02220 RESAUT + 0.05607 HMUNIT - 0.37454 TOUAUT	0.7790
Non-home-based	0.03866 TOTPOP - 0.04400 TOTAUT	0.7519
Attraction		
Home-based work	0.06725 HMUNIT + 0.07019 TOTEMP	0.7751
Home-based shop	0.37704 GMEMP + 0.07525 COMEMP	0.6206
Home-based social-recreational	0.00730 RESDU + 0.04891 HMUNIT + 0.07711 ED + AR	0.6669
Home-based school	0.37470 ENJRHS + 0.51166 ENSRHS + 0.17347 ENOTH + 0.04729 ENCOLL	0.8240
Home-based Miscellaneous	0.01344 HMUNIT + 0.05057 COMEMP	0.6694
Non-home-based	5.19916 + 0.20525 HBATTR	0.6844

Home-Based Social-Recreational Trips

The direct trip generation approach allows this particular trip purpose to be quantified separately rather than aggregated with other trip purposes as was done in the earlier MUATS model development work. This is especially important in Dade County where tourists, who might be expected to make a substantial proportion of social and recreational trips, represent a sizable minority of the winter season population.

The equation for social and recreational captive transit trip productions includes the same independent variables as the shopping trip production model—resident dwelling units, hotel and motel units, and resident and tourist automobile ownership rates.

The final estimating equation for social and recreational captive transit trip attractions includes 3 variables. The first, residential dwelling units, provides a measure of the visits made by friends and relatives. The second variable, hotel and motel units, is directly related to the social and recreational activities of tourists, and the third variable—eating, drinking, amusement, and recreational employment—is a measure of the social and recreational activity within a zone.

Home-Based School Trips

The equation that estimates school transit trip productions is similar to the work-trip model in that it is applicable only to the residents of the area. Initial model development attempts that included an automobile ownership variable were not successful, and it was necessary to define the relationship with only 1 variable—resident population. The failure of the automobile ownership variable to enter the equation can be attributed to the relatively young age of the school trip-makers. Junior and senior high school students, who constitute the overwhelming majority of school travelers, are by virtue of their age unable to drive and are, therefore, unaffected by the number of automobiles available to a household.

As might be expected, 4 school enrollment variables—junior high, senior high, college, and other—are included in the school transit trip attraction estimating equation. The first 2 variables, junior and senior high school enrollments, account for the great majority of school transit trip attractions, but the remaining 2 enrollment categories—college and other—are statistically significant and are included to complete the spectrum of the student trip-making population.

Home-Based Miscellaneous Trips

The miscellaneous captive transit trip production model includes the same 4 variables as the shop and social and recreational trip production models—resident dwelling units, hotel and motel units, and resident and tourist automobile ownership rates. This appears to be logical, and the resultant degree of correlation and the signs of the regression coefficients are also acceptable.

The inclusion of hotel and motel units and commercial employment in the miscellaneous captive transit trip-attraction model results in an equation that is responsive to logical measures of miscellaneous trip activity.

Non-Home-Based Trips

As the term implies, this trip category includes all travel within the study area in which neither trip end (production or attraction) is the home of the trip-maker. Numerous combinations of variables were considered during the development of the captive transit trip-production model, but most were rejected because of the low amount of explained variation. The final selected equation is similar to the other trip production formulas in that a demographic measure (in this case, total population) is directly proportional to the dependent variable whereas total automobile ownership is inversely proportional. Unsuccessful attempts were made to stratify population and automobile ownership by residents and tourists to obtain separate regression coefficients. Finally, the variables were aggregated for use in the model.

An investigation of the variables influencing the non-home-based captive transit trip attractions indicated that they were the same as those used in the other home-based trip attraction models. A similar conclusion was reached by MUATS in the calibration of the total person trip model in this trip-purpose category. In view of this, the final model is directly related to the sum of all other home-based captive transit trip attractions in each zone.

Statistical Analyses of Captive Transit Models

Although the coefficient of correlation is an important statistical measure that provides an initial valuation of the model's acceptability, several other tests were also performed to evaluate the various captive transit trip-estimating equations. One key statistical test procedure is the F-ratio test that determines whether the model is a significant fit of the data. The F-test compares the variability about the fitted independent variables (numerator in F-ratio) with the inherent variability of the dependent variable (denominator). A computed value greater than the tabulated F-ratio for given conditions—degrees of freedom and level of confidence—indicates a significant fit. At the 95 percent confidence level, the computed F-ratio exceeded the tabular value for all captive transit models, denoting significant fits, as given in Table 3.

Another statistical measure of the trip-estimating equations is the t-test on the regression coefficients. This statistic is used to accept or reject the null hypothesis that a regression coefficient is equal to 0. The implication of the 0 condition is that the independent variable contributes nothing to the equation; i.e., any quantity times 0 equals 0. The results of this investigation (Table 3) indicated that the coefficient of each independent variable in all of the models is significant.

The final testing of the models consisted of evaluating the equations under base year conditions and comparing these results with the total number of actual transit trips. As given in Table 4, all trip models except the home-based social-recreational models slightly underestimate captive transit travel. The social-recreational trip models overestimate captive transit trips by 14.9 percent, but this error is insignificant when viewed in relation to the total pool of almost 174,000 trips. The models, with an overall predictive discrepancy of less than 3 percent in terms of total transit trips, are accurate simulators of existing captive transit travel.

CHOICE TRANSIT MODAL-SPLIT MODELS

The choice transit rider is the person who has an automobile available for his trip and can make the trip by automobile but for some reason or combination of reasons decides to use transit. The choice rider differs from the captive rider in that the relative attractiveness of the 2 alternate travel modes—transit and highway—has a significant effect on mode choice. In view of this, it is obvious that any models developed to forecast choice transit ridership should include some measure of the relative performance of the respective transportation systems (e.g., automobile travel time versus transit travel time).

The trip interchange modal-split technique was used in the development of the choice transit use models because this procedure is more responsive to specific improvements in the transportation system. Of interdistrict total person-trips, that proportion that is choice transit oriented is the dependent variable in this modal-split procedure. As a first step in the model-development phase, stepwise linear regression was performed on the district interchange data bank. The results of this initial computer analysis indicated that the number of trip categories should be consolidated. The home-based work and shop trip categories were kept separate, but all other nonschool purposes (including non-home-based) were combined. Because the number of choice school transit trips totaled less than 1 percent of the captive school transit trips, this trip-purpose category was excluded from further analysis.

Additional statistical investigation revealed that the work-trip model should include the travel time ratio (transit travel time divided by automobile travel time) and total employment density. Similarly, the shopping modal split was best explained by the travel-time ratio and commercial employment density. The last model, an aggregation of home-based social-recreational, miscellaneous, and non-home-based trip purposes correlated best with the travel-time ratio, total employment density, and the ratio of

TABLE 3

STATISTICAL ANALYSIS—CAPTIVE TRANSIT TRIP-GENERATION EQUATIONS

Trip Category	Variable	T-Test		F-Test	
		Computed	Tabular[a, b]	Computed	Tabular[a]
Production					
Home-based work	LABFOR	19.23	1.96	475.94	3.02
	RESAUT	10.12	1.96		
Home-based shop	RESDU	9.39	1.96	274.79	2.39
	RESAUT	3.76	1.96		
	HMUNIT	10.34	1.96		
	TOUAUT	5.49	1.96		
Home-based social-recreational	RESDU	5.77	1.96	134.42	2.39
	RESAUT	3.12	1.96		
	HMUNIT	6.71	1.96		
	TOUAUT	3.03	1.96		
Home-based miscellaneous	RESDU	9.91	1.96	172.85	2.39
	RESAUT	7.05	1.96		
	HMUNIT	4.56	1.96		
	TOUAUT	2.53	1.96		
Home-based school	RESPOP	29.39	1.96	863.88	3.86
Non-home-based	TOTPOP	16.86	1.96	292.74	3.02
	TOTAUT	7.16	1.96		
Attraction					
Home-based work	HMUNIT	6.82	1.96	338.54	3.02
	TOTEMP	20.09	1.96		
Home-based shop	GMEMP	10.51	1.96	140.92	3.02
	COMEMP	8.51	1.96		
Home-based social-recreational	RESDU	3.11	1.96	119.85	2.62
	HMUNIT	10.45	1.96		
	ED + AR	3.27	1.96		
Home-based miscellaneous	HMUNIT	3.78	1.96	182.69	3.02
	COMEMP	16.65	1.96		
Home-based school	ENJRHS	13.82	1.96	236.90	2.39
	ENSRHS	24.47	1.96		
	ENOTH	2.85	1.96		
	ENCOLL	6.17	1.96		
Non-home-based	HBATTR	19.91	1.96	396.45	3.86

[a]All tabular values are based on a 95 percent confidence interval.
[b]For large degrees of freedom, the t-statistic is very nearly the same as the Z or standard normal distribution.

total persons to total dwelling units. Even though the included variables in each of the respective equations appeared logical in terms of explaining the selection of travel mode, the degree of correlation was low. Further study of the degree of correlation of travel-time ratio with percentage of transit use indicated that a set of competitive diversion curves would be applicable in the Dade County area. The other explanatory variables identified in the respective equations would be included as parameters to the diversion concept. Because the diversion curve technique generally leads to a curvilinear relationship, linear regression was abandoned.

TABLE 4

COMPARISON OF ACTUAL AND ESTIMATED CAPTIVE TRANSIT TRIPS

Trip Category	Actual	Estimated	Difference (percent)
Home-based work	45,854	45,452	-0.9
Home-based shop	14,998	14,955	-0.3
Home-based social-recreational	8,606	9,893	+14.9
Home-based school	60,490	56,010	-7.4
Home-based miscellaneous	12,460	12,208	-2.0
Non-home-based	31,454	30,916	-1.7
Total	173,862	169,434	-2.6

This type of nonlinear approach has been commonly referred to as curve fitting because the data are plotted and curves are drawn through the points to reflect the modal-split relationship. Several regional transportation studies have used this method when linear relationships were not believed valid or could not be quantified from the data. This approach has an additional advantage in that it allows the planner to examine the data carefully and devise various stratifications of the source information.

The curve-fitting approach is iterative in that initial sets of curves are developed and tested for their ability to replicate existing transit travel. The curves are revised on the basis of the differences between actual and estimated transit travel and subsequently retested. The process of curve fitting and testing is repeated until accurate curves or models are obtained.

As shown in Figure 2, the final selected curvilinear models relate the travel-time ratio (transit versus automobile) to the proportion of total interdistrict travel demand that is choice transit travel. The curves for all 3 trip-purpose categories are similar in that they are curvilinear, and the travel-time ratio is inversely proportional to the percentage of transit-oriented travel. The work and shopping trip curves are stratified by the level of total employment density and commercial employment density respectively. The model for the other trip-purpose category conformed to the general shape of the curves for the work and shopping trip models. For this model, the data were stratified further by inclusion of a production end variable—total persons per total dwelling units.

TABLE 5

COMPARISON OF ACTUAL AND ESTIMATED CHOICE TRANSIT TRIPS

Trip Category	Coefficient Correlation	Actual	Estimated	Difference (percent)
Work	0.7752	6,014	6,529	+8.6
Shop	0.8521	2,274	2,160	-5.0
Other[a]	0.7785	7,254	7,072	-2.5
School	-	444	-	-
Total		15,986	15,761	-1.4

[a]Aggregation of home-based social-recreational, miscellaneous, and nonhome-based.

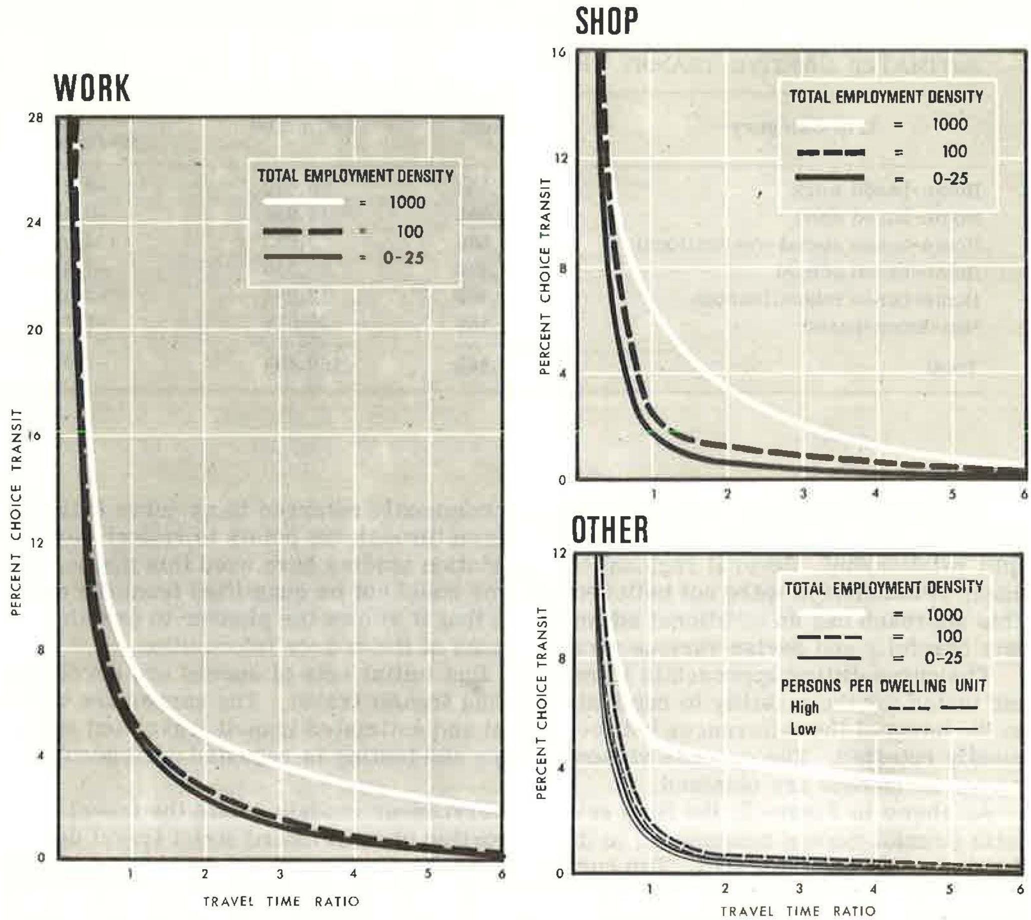

Figure 2. Choice transit modal-split curves.

Although the models appear logical and seem to explain the true causal relationship between transit use and the various travel-related variables, it is also of prime importance that they be able to simulate actual base year (1969) choice transit travel. One important measure of this ability is the coefficient of correlation that measures the amount of explained variation. This statistical term was computed by comparing the actual choice transit trips (1969) to the totals obtained by applying the curves to the respective 1969 total person-trip matrices on the basis of existing socioeconomic, land use, and transportation system conditions. As given in Table 5, the coefficients of correlation indicate a statistically good and significant relationship between the models and the real world. Table 5 also gives data showing that the discrepancy between actual and estimated choice transit trip totals ranges from a low of -2.5 percent for the other trips to a high of +8.6 percent for work trips. The overestimation of work trips almost balances the underestimation of the 2 remaining trip-purpose categories with a resulting error of less than 1-1/2 trips per hundred.

Another test of the models involved a comparison of the trip-length distribution for actual and estimated conditions. As shown in Figure 3, the trip-length distributions for all 3 transit trip purposes are very nearly the same. In addition, the differences between average trip lengths—actual and estimated—are within reasonable limits for all 3 trip-purpose categories. The largest discrepancy (4.7 percent) is found in the

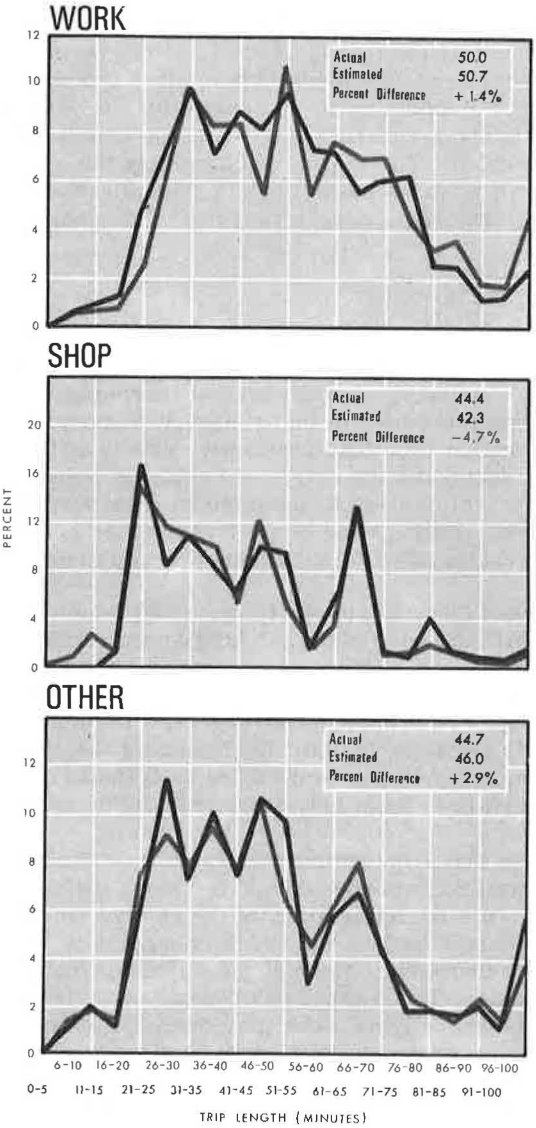

Figure 3. Choice transit trip-length distribution—actual versus estimated.

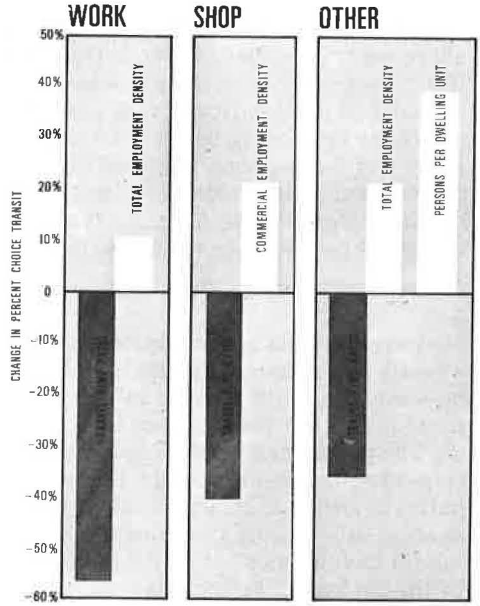

Figure 4. Reaction of percentage of choice transit to a 50 percent increase in travel-related variables.

shopping trip category, which also has the shortest average trip length. On the other hand, the work trip category has the smallest difference (estimated versus actual) and the longest average trip length. In general, it appears that all models adequately reproduce existing transit travel patterns as measured by trip length.

The previously discussed tests examined the ability of the models to simulate existing conditions. The assumption throughout is that, if the relationship quantified for 1 set of environmental conditions (1969) is valid, it will hold true for some future point in time—1985, for instance. Of prime importance in this particular analysis is how well the models respond to changes in study area conditions--specifically the transportation system. It was the failure of the 3 previous modal-split models in this area that prompted the investigation of the possibility of developing 2 sets of models.

One method used to gage model sensitivity to changes in each of the independent variables is to increase (or decrease) the value of each of the variables 50 percent above (or below) existing levels and then measure the impact on transit use (as defined by the percentage choice transit is of total person travel demand). Figure 4 shows that the travel-time ratio (transit or automobile) does indeed have a significant impact on percentage of choice transit trips. For example, a 50 percent increase in the travel-time ratio results in a 57 percent decrease in the percentage of choice work transit trips whereas, on the other hand, a 50 percent increase in employment density yields only a 10 percent increase in the proportion of work transit trips. Similarly, the shopping trip model is also influenced the most by the transportation system variable (i.e., the travel-time ratio), whereas commercial employment density plays a lesser although still significant role in determining the modal split. A sensitivity analysis of the other trip-purpose model shows that it is about equally sensitive to the travel-time ratio and the persons per dwelling-unit variables. The impact of changes in the employment density variable in this model is not so great as that of the other 2 variables, but it is significant. This analysis indicated that models were responsive to changes in the included independent variables.

CONCLUSION

Various tests and analyses indicated that both the captive and choice modal-split models are reasonable and logical in terms of the included independent variables and statistically valid and capable of accurately simulating existing transit travel patterns. In addition, the choice models are responsive to changes in the transportation system.

The procedure of developing direct-generation equations for captive riders and trip-interchange models for choice riders recognizes the extremely different behavior patterns of the 2 groups in allocating their travel demand to the bimodal transportation system—the supply of transportation services. Segregation of the transit trips prior to model development permits the distinct characteristics of each transit group to emerge in their respective models.

This is especially important in urban areas that are currently served by buses traveling over congested city streets and that may have plans for high-speed rapid transit systems. Modal-split models in which transit riders are treated as a single group are calibrated from a transit trip-making population that is predominantly captive. It is questionable whether the modal-split relationships will be valid in future years for which major transit improvements are to be tested. Evaluation of the captive-choice formulas for Dade County with a comprehensive network of rapid transit facilities produced a shift in the dichotomy of transit patrons from only 1 choice rider in every 8 transit patrons in 1969 to 1 in 3 in 1985.

An additional benefit of the dual models is that 2 inventories of transit travel are available for study in future years. The travel movements of captive riders indicate where service must be supplied to accommodate the aspirations of the captive riders with regard to work, shopping, and social-recreational needs. This is especially important today when planners are more aware than ever before of the impact of mobility and its social consequences on urban residents. On the other hand, detailed analysis of the choice trips identifies those corridors where transit can play the most effective role in taking people from their cars and reducing the congestion on an already overburdened highway system.

The development of the 2 travel models—direct generation for captive riders and trip interchange for choice riders—appears to be a new and useful technique in evaluating transportation alternates of the future. The exploration of this approach in other cities would provide a useful data bank to evaluate more fully this approach and its applicability to other urban areas.

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