DISAGGREGATED MODAL-CHOICE MODELS OF DOWNTOWN TRIPS IN THE CHICAGO REGION

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Modal-choice models that combine both regional and behavioral aspects were successfully developed and calibrated for the Chicago area. The regional aspects include the coverage of trip origins throughout the entire Chicago area and the zonal nature of the data. Aspects of the models typical of disaggregated and behavioral modal-choice models are the form of the dependent variable (a dummy indicating the mode chosen) and the analytic functions used (logit and probit). Using a dummy for the dependent variable solves the problems of errors in the dependent variable and of aggregation of values of the independent variables. Probit and logit analyses restrict the value of the dependent variable suitably and are consistent with expected behavioral patterns. The independent variables chosen reflect characteristics of travelers and of the modal options available for a particular trip. These models were designed to be used both as part of the urban transportation planning package for the Chicago region and as regional planning and policy evaluation tools by themselves.

•THIS report presents the results of the calibration of modal-choice models designed to be used as part of the urban transportation planning (UTP) package for the Chicago area and also as regional planning and policy tools by themselves. The models, which to date have been calibrated only for downtown trips, combine aspects of both regional and individual behavioral modeling. Regional facets of the analysis are the coverage of trip origins throughout the entire Chicago area and the zonal nature of the data. The analytic method, the form of the dependent variable, and the choice of the variables are individual and behavioral in nature.

Because the analysis is designed to be part of a regional UTP package, the coverage of the data must include the entire region and not just a transportation corridor or some other subarea as in individual behavioral models. Therefore, zonal data are average data for the zones, and transportation system characteristics are calculated from zone centroid to zone centroid.

The individual behavioral aspects of the analysis include the choice of the analytic functions and the form of the dependent variables. The functions chosen for this analysis are logit and probit functions. They are appropriate because they restrict the values of the dependent variable between 0 and 1 and because the plotted data appear to follow the form of the curves they yield.

The form of the dependent variable in probit or logit analyses can either be the percentage of the particular modal split between an origin and destination pair (interchange) or be a dummy indicating the actual modal choice for the individual sampled trips. The former treats the modal split between 2 zones as the dependent variable; the latter treats the modal choices of individual trips. Because of the small number of trips between most origin and destination pairs in regional analysis, the modal split of an interchange is subject to large errors and is, therefore, a poor choice for the dependent variable. In addition, if interchange splits were used, they should be weighted by the

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actual number of trips for aggregation of values of the independent variables so that bias in the data is avoided. For those 2 reasons, the mode of the individual trips is the dependent variable used here.

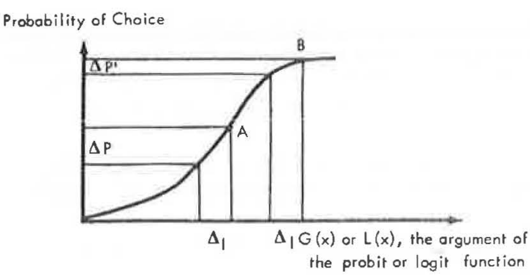
The independent variables in this analysis have been used in both regional and individual behavioral models. They reflect the characteristics that have been found to be important in individual modal-choice decisions. The variables describe the trip-maker, e.g., income, and also the particular trip, e.g., distance traveled, travel times, and travel costs.

The particular combination of regional and individual modeling used in this analysis makes possible the calibration of regional modal-choice models with increased realism and, therefore, the better ability to project future travel demands and to estimate the effects of policy and planning changes on those travel demands. Because the sample is drawn from the entire region, the results are not specific to any subarea within the Chicago area. The choice of logit and probit analyses as tools increases the realism of the model and also the accuracy of prediction to changes in the transportation system. The form of the dependent variable, a dummy indicating the choice of mode for individual trips, eliminates the problems of errors in the dependent variable and of biases in the data. The choice of the independent variables results in models that are sensitive to changes in the transportation system inasmuch as travel times and costs depend on the transportation options available between zones. Finally, the results may well be generalized to other metropolitan regions because of the behavioral nature of the analysis.

THEORY AND VARIABLES

The theoretical bases of this research are those usually found in behavioral, disaggregated modal-choice models. The distinctive features of the method are the choice of the functions used in the analysis, the form of the dependent variable, and the choice of the independent variables.

The analytic tools used in this study are probit and logit. Because possible values of the dependent variable lie between 0 and 1, a function with those limits must be found. Both the probit, or cumulative normal, and the logit functions have this characteristic. They yield S-shaped curves as shown below. The shapes of these curves are very similar although the functions themselves differ. Mathematically expressed, the probit function is



$$P = \int_{-\infty}^{G(x)} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}t^2} dt$$

and the logit function is

$$P = \frac{e^{L(x)}}{1 + e^{L(x)}}$$

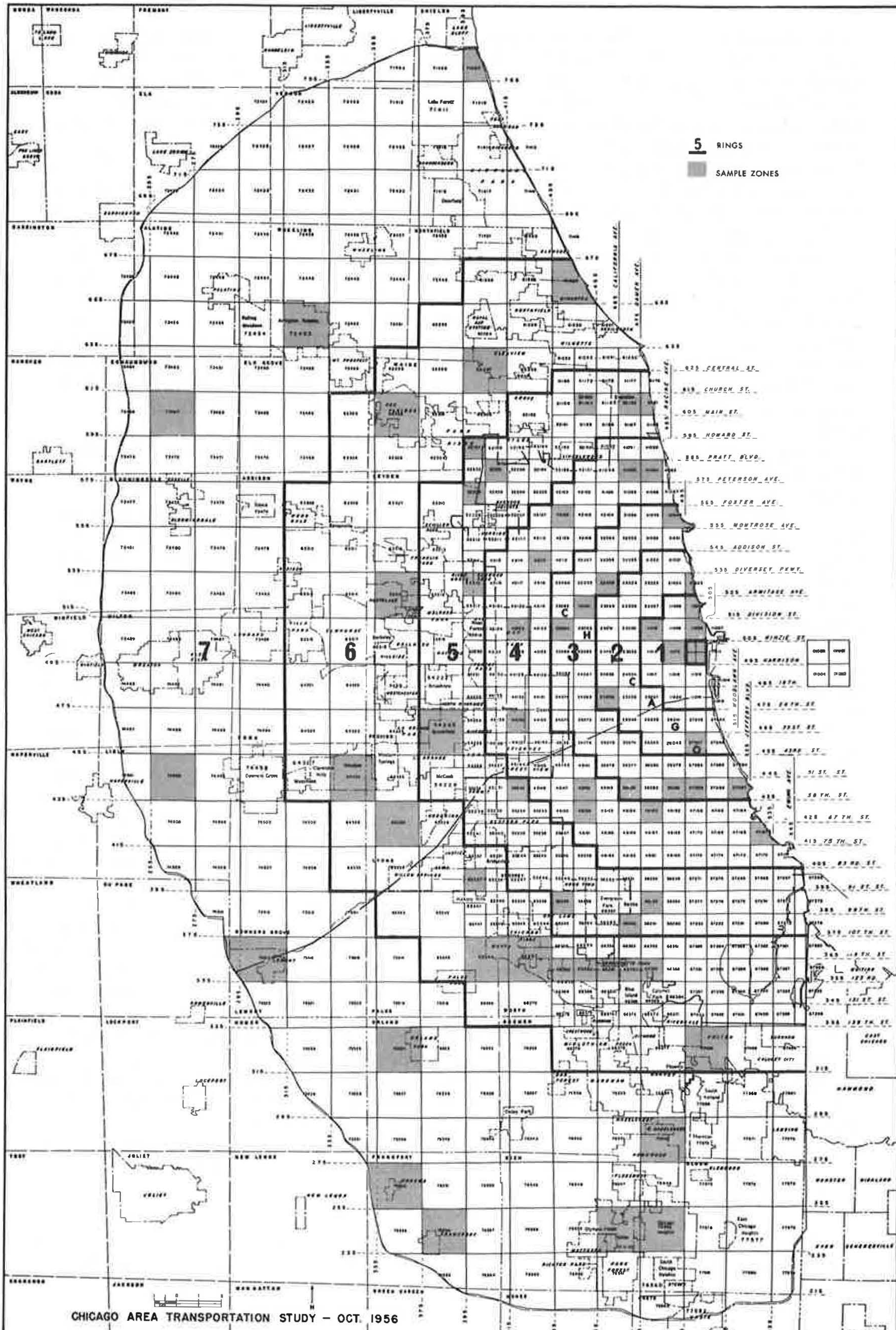
where G (x) and L (x) are linear or nonlinear functions of the independent variables, and P is the probability of modal choice.

Those functions also follow expected behavioral reactions. The effects on modal choice of given differences in travel times and costs are expected to be larger near the point of indifference between modes than at points of definite preference, where the probability of modal choice approaches 0 or 1. For example, let no preference for either mode exist at A (Fig. 1) and a definite preference exist at B. If, for example, rail travel times increase by the same amount at both A and B (Δ_1), then the expected response at A(ΔP) is greater than the expected response at B(ΔP$'$).

The probit and logit functions also appear to be well specified, for the data follow the shapes of these particular S-curves.

For several reasons, in this analysis, as in disaggregated modal-choice analysis, the dependent variable is the modal choice of each trip instead of the modal split of all

Figure 1. Chicago Transportation Study region.



trips between 2 zones. First, the mode chosen is exactly known, while the modal split of an interchange is subject to large errors because of the small number of trips sampled for any interchange. Errors in the dependent variable result in problems of estimation that are not easily solved; the use of individual trips avoids this problem. Also their use facilitates the estimation of the mode of travel for given values of the independent variables as other factors are held constant. The unit of analysis is the trip for modal-choice analysis and the zonal interchange for modal-split analysis. Aggregation for the region results in summing trips in the first case and in summing zones in the second, unless zonal interchanges are used as weights in the summation.

Another type of weighting problem not entirely solved in this analysis occurs through the use of binary-choice models in a multimodal context. In an effort to compensate for this, we made 2 alternate assumptions concerning the structure of modal choice. First, it is assumed that each traveler makes pair-wise comparisons between modes until he decides on a mode. He considers the bus and rail modes separately as alternatives to the automobile and also to each other. Under that assumption, the sample includes all trips by either mode being analyzed. A second assumption, investigated separately, is that travelers decide first between automobile and transit modes and, then, after that initial automobile-transit decision, between the specific public transit modes.

Those 2 assumptions about traveler behavior require the definition of 3 specific and 1 combination mode: car, rail, bus, and other. The car mode was always an alternative, so it was always included in the binary-choice analysis. The rail mode includes both suburban railroad and subway (or elevated) rapid transit. Both have similar access characteristics in relation to line-haul characteristics. The stations are relatively far apart, so access costs are important. Also, line-haul travel is not in conflict with private automobile transportation, and thus congestion (as more cars enter the system) has no effect on line-haul travel. For the same reason, all public transit modes that use streets were included in the bus mode. This includes both local and express service throughout the Chicago region. The frequency of bus stops and the conflict of line-haul travel with the car mode distinguish it from the other specific transit mode. For the alternate assumption about modal-choice behavior, both public transit modes, rail and bus, were combined into an other mode.

Trips were stratified by purpose: work and nonwork. It has frequently been found that characteristics of trips associated with purpose affect the relative importance of other factors. It has been hypothesized that the repeated nature of work trips allows more thorough analysis of alternatives by workers than by others for whom the trip is infrequent. According to this reasoning, behavioral adjustment for work trips will be relatively complete because work trips continue during long periods. It is expected that behavioral adjustment will be less complete for nonwork trips because information is less complete and each trip occurs less frequently.

The specific independent variables used in the analysis are alternate times and costs, income, and trip distance. Relative travel times and costs are both explicit comparisons of modal characteristics to which travelers react. In this research, cost and time differences were used instead of ratios, an alternate method of comparison, because differences are more easily understood and several recent studies have shown that differences do a better job in explaining modal-choice behavior.

Income is included because it imposes economic limits on the amount that can be spent in efforts to save time and to increase total travel utility.

The importance to modal choice of certain factors, such as relative comfort between modes, may change with increasing distance traveled. Because comfort is hard to quantify separately, distance is assumed to be in part a proxy for it.

The constant term may be viewed as a measure of travelers' initial "bias" toward one mode or the other based on initial differential levels of comfort and convenience between modes.

DATA

The data used in this analysis are based on the CATS home interview study in 1956. The survey included a 1-in-30 sample of households in the Chicago area shown in

Figure 2. A nonrandom sample of zones was selected to keep the sample size manageable while sufficient variation in the independent variables was maintained. Sixty-one origin zones were selected from the entire region. The 6 destination zones cover the Chicago central business district (CBD). Sample sizes and average statistics for each modal choice and purpose are given in Table 1. The zones chosen are shown in Figure 2. The trip source is the actual unfactored trips from the home interview survey. Specific data items are discussed below.

Modal Choice

In modal-choice analysis, the dependent variable is 0 or 1 depending on the choice made. The automobile choice is always 1 in this analysis; the transit is 0. The transit mode is the rail mode, the bus mode, or, in the case of the other mode, the sum of the rail and bus modes.

Car Travel Times

For car travel, speeds by ring were estimated from travel times by ring to the CBD reported in the home interview survey. The car travel times in minutes were then derived from distance traveled in each ring and the estimated speed in that ring.

Public Transit Travel Times

Travel times by public transportation were estimated in minutes on the basis of line-haul time plus an estimate of access and egress times. Line-haul travel time was estimated from schedules and, if schedules were unavailable, from the 1965 CATS assignment network. Travel time by the other mode is a weighted average of the times for the specific modes. The weights are the modal splits between the bus and the rail modes. Access times were based on the walk mode unless the train station or bus stop was more than 1 mile from the centroid of the zone. In that case, access was assumed to be by car (this is consistent with the assumptions made for travel costs). Egress time downtown was always based on an assumed choice of the walk mode.

Car Travel Costs

Car travel costs were estimated in cents using distances estimated, an estimate of cost per mile (3.5 cents/mile), an estimate of the prorated cost of owning a car (32 cents/1-way trip), and half the estimated parking fee in the destination zone. The prorated cost of owning a car is the depreciation expense attributable to the trip. Parking fees in the CBD are the largest single component of car-driving costs for trips to the CBD. The values used were an interpolation of the all-day (or 8-hour) fees reported in 1948 and 1962.

Public Transit Travel Costs

Cost data were obtained from the Illinois Commerce Commission for the public transit modes. They are the 1956 fares in cents. Costs for the other mode are calculated in the same way as travel times. If the train station or bus stop was more than 1 mile from the centroid of the zone, access costs were added to the line-haul fare. Because actual mode of access to the station was not known, the access mode was assumed to be car. Capital costs were 32 cents (1-way) plus 3.5 cents/mile (parking fees were 0 at suburban stations in 1956).

Differences in Travel Costs and Times

Cost and time differences (ΔC and ΔT) were calculated by subtracting the transit travel cost or time from the automobile travel cost or time.

Income

An estimate of the average income in dollars for the families in the zone of origin was obtained from 1960 census data. Because relative income levels among zones rather than actual levels of income are the relevant income characteristic, the difference in data (1956 versus 1960) was not considered important.

Distance

Distances from the centroid of the origin zone to the centroid of the destination zone by highway were estimated in miles; the highway network existing in 1956 was used. Distance along highways was chosen rather than airline distance to reflect the differing accessibilities of areas with the same airline distance from the CBD.

ANALYSIS

Analysis of modal choice was separated by trip purpose—work and nonwork—and, for each purpose, by binary choice—car-rail, car-bus, and car-other. Graphical analysis of the data for each choice was completed first to obtain preliminary indications of the effect of individual independent variables on modal choice and to check the specification of the functions. Subsequently, various combinations of the 4 independent variables were tried in multivariate binomial probit and logit analyses. Those 2 functions yield results that are virtually identical despite differences in the values of the coefficients. Choice of technique is, therefore, a matter of taste. In the logit and probit analyses, the reliability of the coefficients and the importance of the variables were examined through the values of the standard errors of the coefficients and the value of $-2\ln\lambda$, the likelihood ratio test. The reasonableness of the coefficients was measured by using them to derive the marginal values of time and comfort and comparing them with values derived from other research. After the values of the coefficients were determined to be both statistically significant and reasonable, the relative importance of the variables among the binary choices and between trip purposes was studied, and possible reasons for differences were advanced.

Work Trips

Car-Rail Choice—Scatter diagrams of the data were drawn on normal probability paper to determine whether the postulated relations for the variables considered individually existed. Each datum point plotted consists of the percentage of car choice for about the same number of trips. If the relations were actually the S-curve specified by the probit function, then the data points would all be on a straight line. Two examples of these graphs, shown in Figures 3 and 4, illustrate the marginal effects of ΔT and ΔC on modal choice. The data points do not diverge significantly from the postulated straight line. The deviation of the actual data points from the estimated line has 3 sources. One is the true randomness in the response of individuals to a situation. The second is due to the effects of variables not included in the graphical analysis although included in later functional analysis. The third is variables omitted from the analysis.

The coefficients from logit and probit analyses for the car-rail choice for work trips are given in Table 2. Also shown are t-values, the coefficient divided by the standard error. If the t-value is 2 or greater, then, if the assumptions behind the models are correct, the coefficients differ from 0 with a probability of at least 0.98. The generally high significance (high t-values) for the coefficients of ΔC and ΔT indicates the reliability of those coefficients. The low t-values for income and distance indicate the likely lesser importance of those factors, as measured. The values of $-2\ln\lambda$ given in Table 2 confirm those results.

The signs of the coefficients of ΔC and ΔT are as expected. Increased travel cost or time for a mode results in a decreased probability of that mode being chosen. If the value of ΔC is increased by 20 cents above the average value of ΔC (\$1.10), the probability of the car choice decreases from 0.55 to 0.50. An increase in the value of ΔT by 10 min above the average value (approximately 0 min) decreases the probability of the car choice from 0.55 to 0.48. [These changes were calculated for average values of all the other variables (see Table 3)]. As ΔC and ΔT take on more extreme values, the calculated induced change in the probability of modal choice decreases because of

Table 1. Selected characteristics of samples analyzed.

Trip	Sample	Car Trips Number	Car Trips Percent	Avg Income (dollars)	Distance (miles)
Work					
Car-rail	1,314	685	52	8,400	10
Car-bus	1,518	732	48	7,800	8
Car-other	2,179	766	35	8,000	9
Nonwork					
Car-rail	756	565	74	8,000	8
Car-bus	1,037	586	57	7,500	7
Car-other	1,242	596	48	7,600	7

Figure 2. Data points and estimated probit curve for car-rail work trips to CBD—only ΔT controlled.

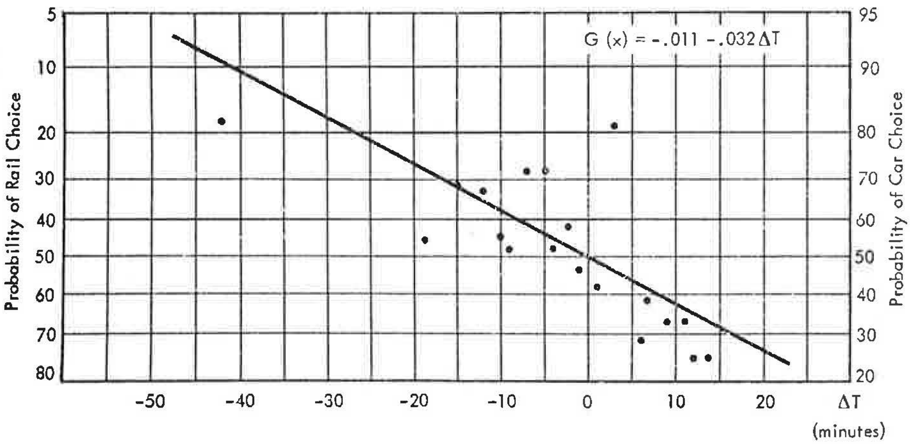


Figure 3. Data points and estimated probit curve for car-rail work trips to CBD—only ΔC controlled.

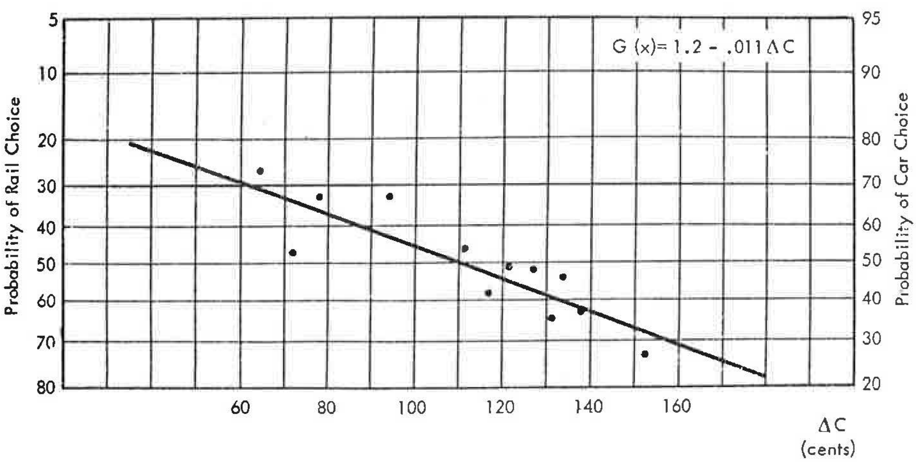


Table 2. Regression coefficients, standard errors, and t-values of car-rail work trips to CBD.

Equation	Probit Analysis Constant	ΔC	ΔT	Income	Distance	$-2\ln\lambda$[a]	Logit Analysis Constant	ΔC	ΔT	Income	Distance
Coefficient											
1	1.23	-0.011				71	1.98	-0.017			
2	-0.011		-0.032			96	-0.015		-0.052		
3	0.0076			0.55×10^{-5}		0.37	0.012			0.87×10^{-5}	
4	-0.015				0.0068	1.5	-0.023				0.011
5	0.69	-0.0062	-0.024			115	1.12	-0.010	-0.040		
6	0.75	-0.0058	-0.026	-1.2×10^{-5}		115	1.21	-0.0094	-0.042	-2.0×10^{-5}	
7	0.69	-0.0068	-0.023		0.0063	115	1.13	-0.011	-0.038		0.011
8	0.76	-0.0063	-0.024	-1.5×10^{-5}	0.0070	116	1.23	-0.010	-0.040	-2.4×10^{-5}	0.012
Standard Error											
1	0.15	0.0013					0.24	0.0021			
2	0.036		0.0033				0.058		0.0055		
3	0.14			1.6×10^{-5}			0.22			2.5×10^{-5}	
4	0.071				0.0061		0.11				0.0098
5	0.17	0.0014	0.0037				0.27	0.0023	0.0061		
6	0.19	0.0016	0.0041	1.9×10^{-5}			0.30	0.0026	0.0068	3.0×10^{-5}	
7	0.17	0.0016	0.0040		0.0070		0.27	0.0026	0.0066		0.011
8	0.19	0.0017	0.0043	1.9×10^{-5}	0.0070		0.30	0.0027	0.0071	3.0×10^{-5}	0.011
t-Value											
1	8	8					8	8			
2	0.3		9				0.3		9		
3	0.1			0.3			0.06			0.3	
4	0.2				1.1		0.2				1.1
5	4	4	6				4	4	6		
6	4	4	6	0.7			4	4	6	0.7	
7	4	4	6		0.9		4	4	6		1
8	4	4	6	0.8	1		4	4	6	0.8	1

[a]Values are the same for logit and probit analysis.

Table 3. Effect on probability of car choice of changes in value of independent variables.

Trip	ΔC Increased 20 Cents From	To	Change	ΔT Increased 10 Min From	To	Change	Distance Increased 1 Mile From	To	Change	Income Increased $1,000 From	To	Change
Work												
Car-rail	0.55	0.50	0.05	0.55	0.48	0.07	—[a]	—[a]		—[a]	—[a]	
Car-bus	0.49	0.44	0.05	0.49	0.45	0.04	0.48	0.52	0.04	0.46	0.49	0.03
Car-other	0.35	0.30	0.05	0.36	0.32	0.04	0.32	0.34	0.02	0.34	0.36	0.02
Nonwork												
Car-rail	0.79	0.72	0.07	0.80	0.73	0.07	—[a]	—[a]		—[a]	—[a]	
Car-bus	0.59	0.51	0.08	—[a]	—[a]		0.56	0.59	0.03	0.56	0.59	0.03
Car-other	0.52	0.44	0.08	—[a]	—[a]		0.46	0.48	0.02	0.46	0.49	0.03

Note: Eq. 8 was always used.

[a]Coefficients were not significantly different from 0 at the 0.96 level.

the S-shaped curve used for analysis. The coefficients of both distance and income are small in relation to the sizes of the standard errors. Therefore, nothing can be said about them for this choice.

A check on the reasonableness of the coefficients of ΔC and ΔT was made by calculating the marginal value of time. The calculated marginal value of time is actually the amount the typical commuter to the CBD in 1956 was willing to pay to travel by a specific faster mode. The estimate for the car-rail choice for work trips is approximately \$2.30/hour. That estimate is consistent with other estimates of the marginal value of time and, therefore, provides an additional check on the sizes of the coefficients.

From the constant term and average values of income and distance traveled, a type of marginal "value of comfort" can be calculated. That is the amount people are willing to pay for the preferred mode if times and costs of the alternate modes are the same and if bus trips are ignored. The calculated marginal value of comfort includes the additional value of all factors associated with one mode as compared with the other, if trips by the third mode are ignored. In the car-rail choice, this was \$1.10 in favor of the automobile mode.

As a final check to investigate the accuracy of the specification of the analytic functions, actual and predicted probabilities of car choice were plotted as functions of G (x), the argument of the probit function (and, therefore, the estimated optimal weights for the independent variables). That is shown in Figure 5. In this case, the deviation of the actual data from the estimated curve is due only to the effect of random behavior of travelers and variables omitted from the analysis. As expected, the spread of the data points around the estimated regression line is considerably smaller when all variables are controlled than when only 1 variable is controlled (Figs. 2 and 3). There appears to be no problem of specification.

Car-Bus Choice—For the choice between car and bus modes, the estimated coefficients from probit and logit analyses for work trips are given in Table 4. The values of all the coefficients are significantly different from 0 at the 0.98 level including, in contrast with the car-rail choice, the coefficients of income and distance. That may be due to smaller differences in comfort within the bus mode in contrast with the rail mode, which includes both suburban rail and subway or elevated.

The effects of changes in the values of the independent variables are given in Table 3. Those who face the car-bus choice are less sensitive to changes in time and more sensitive to the effects of income and distance than are those who face the car-rail choice. The effect of ΔC, income, ΔT, and distance controlled is about the same. The fact that the coefficient of income is significantly different from 0 in this case indicates that the income constraint is binding.

The reasonableness of the coefficients of ΔC and ΔT was checked by a calculation of the marginal value of time for the typical commuter traveling to the CBD and faced with a choice between car and bus modes. The time value was approximately 70 cents/hour, considerably less than \$2.30 for those faced with a car-rail choice. That is consistent with an income constraint that is binding. Those who face this choice cannot afford to pay so much for their time.

The calculated marginal value of comfort for the typical commuter traveling to the CBD and faced with a choice between car and bus modes, if rail trips are ignored, is about 80 cents in favor of the automobile. That is lower than the value for those faced with a choice between car and rail modes but is consistent with the typical lower income of people who choose between automobile and bus within the same zone; they cannot afford to pay so much for greater comfort. It is also consistent with more frequent departures and more accessible stops of the bus mode, which is more convenient than the rail mode. The greater initial marginal value of comfort for people in the rail-automobile choice group in relation to those in the bus-automobile choice group is calculated to be 30 cents (\$1.10 minus \$0.80).

Car-Other Choice—If the relevant behavioral choice is between private (automobile) and public (bus and rail) modes, then the car-other choice is the relevant binary choice to analyze. The fact that income and distance were unimportant for the car-rail choice but highly significant for the car-bus choice indicates this hypothesis might be

Figure 4. Data points and estimated probit curve for car-rail work trips to CBD—optimal weights for all independent variables.

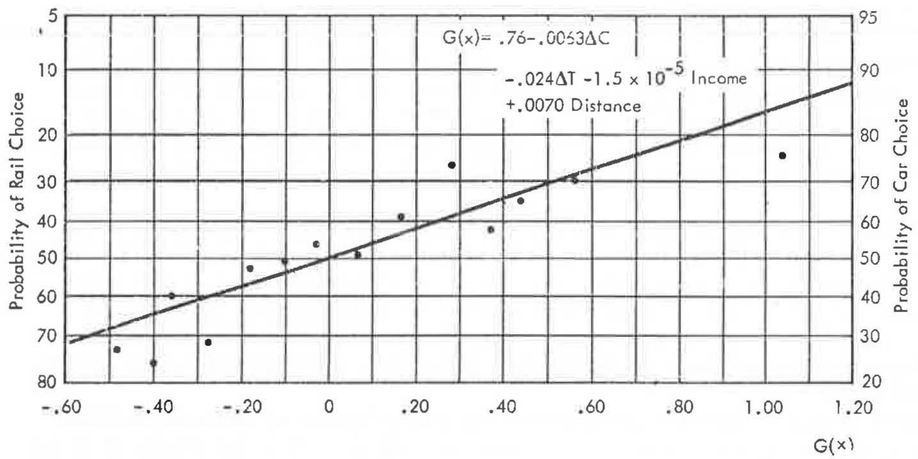


Table 4. Regression coefficients, standard errors, and t-values of car-bus work trips to CBD.

Equation	Probit Analysis						Logit Analysis				
	Constant	ΔC	ΔT	Income	Distance	$-2\ln\lambda$[a]	Constant	ΔC	ΔT	Income	Distance
Coefficient											
1	-0.26	0.0020				4	-0.42	0.0033			
2	-0.39		-0.018			82	-0.62		-0.029		
3	-1.4			0.17×10^{-3}		92	-2.2			0.28×10^{-3}	
4	-0.81				0.095	194	-1.4				0.17
5	-0.56	0.0016	-0.018			84	-0.90	0.0027	-0.029		
6	-1.4	-0.00096	-0.015	0.15×10^{-3}		142	-2.2	-0.0015	-0.024	0.24×10^{-3}	
7	-0.42	-0.0056	-0.0092		0.10	234	-0.69	-0.010	-0.013		0.18
8	-0.89	-0.0063	-0.0083	0.083×10^{-3}	0.088	250	-1.4	-0.011	-0.012	0.13×10^{-3}	0.16
Standard Error											
1	0.12	0.0011					0.2	0.0018			
2	0.050		0.0021				0.082		0.0034		
3	0.14			0.018×10^{-3}			0.24			0.030×10^{-3}	
4	0.067				0.0074		0.12				0.014
5	0.13	0.0011	0.0021				0.21	0.0018	0.0034		
6	0.17	0.0012	0.0021	0.020×10^{-3}			0.27	0.0019	0.0035	0.032×10^{-3}	
7	0.13	0.0013	0.0022		0.0088		0.21	0.0022	0.0038		0.017
8	0.17	0.0013	0.0023	0.021×10^{-3}	0.0091		0.29	0.0022	0.0038	0.034×10^{-3}	0.017
t-Value											
1	2	2					2	2			
2	8		9				8		9		
3	10			9			9			9	
4	12				12		11				12
5	4	1.5	9				4	1.5	9		
6	8	0.8	7	8			8	0.8	7	7	
7	3	4	4		11		3	5	3		11
8	5	5	4	4	10		5	5	3	4	9

[a] Values are the same for logit and probit analysis.

questioned. However, t-tests on the coefficients resulting from logit and probit analyses (Table 5) and the values of $-2\ln\lambda$ all indicate significant results for this mode. The signs of the coefficients are as expected. The effects of changes in values of the independent variables tend to be intermediate between those for the specific choices (Table 3) for the typical commuter.

The calculated marginal value of time is approximately $1.15, also intermediate between the values for the 2 specific choices.

The marginal value of comfort calculated from this analysis for the typical commuter to the CBD is about 35 cents in favor of the car mode. That is less than the values for either specific choice and is due to the combination of all transit trips into one mode in the analysis of car-other trips.

Nonwork Trips

Car-Rail Choice—The results of the probit and logit analyses of the car-rail choice for nonwork trips (Table 6) indicate that the effects of distance and income could be due to chance.

The bases of the calculations of travel costs are the same for nonwork trips as for work trips. As a result, it is probable that the calculated values of ΔC are larger than the actual values. The largest component of car costs, parking fees, is probably less for nonwork trips because the stay in the CBD may be less than a full day. The difference is probably larger than the greater cost of the rail ticket because the rail ticket is bought individually and not as part of a monthly or multiride ticket. Also the number of people traveling together is greater on the average for pleasure trips than for work trips. That would result in smaller costs per person by car. The necessity for this adjustment indicates that choice for nonwork trips is probably more sensitive to changes in ΔC than implied by the calculated coefficients. The values of ΔT for nonwork trips might be modified for the same reasons as postulated for the values of ΔC. In this case, car travel time can be expected to be less because travel is not restricted primarily to peak hours, although the increased search for parking space may partially compensate for this difference. The calculated marginal time values for nonwork trips may be less reliable than that for work trips because of cost and peak—off-peak problems. The calculated value for the car-rail choice is approximately $1.10/hour for nonwork trips and is less than the $2.30/hour for work trips.

The effects on modal choice of changes in ΔC are larger for the average nonwork trip than for the average work trip; the effects of changes in ΔT are about the same (Table 3) even without the adjustments suggested above.

The marginal value of comfort if bus trips are ignored is calculated to be approximately $1.70 in favor of the automobile and is larger than the value for work trips for the same choice. It may be that those who are unfamiliar with the CBD and the transit system and those who make infrequent trips find greater certainty in traveling by car than by public transportation. The effort needed per trip to learn how to use public transit facilities is greater if the trip is infrequent than if it is frequent. Other possible reasons are that the trains run less frequently during off-peak periods and that shoppers may prefer not to carry bags to and from transit.

Car-Bus Choice—All the coefficients of the variables tend to be less significant for the car-bus choice for nonwork trips (Table 7) possibly because of data problems previously discussed. The effect on modal choice for the typical nonwork traveler facing the car-bus choice tends to be larger. The effect of ΔT was not captured for this choice (note the low t-value for the coefficient of ΔT in Eq. 8) probably because of the poor quality of the data. As a result, it was impossible to calculate the marginal value of time for this choice.

The calculated marginal value of comfort ($1.20) is less for the car-bus choice (rail trips ignored) than for the car-rail choice (bus trips ignored). As for the car-rail choice, the value is larger for nonwork trips than for work trips. The calculated marginal value of comfort for the rail mode in relation to the bus mode for nonwork trips is calculated to be 50 cents ($1.70 - $1.20), larger than the 35 cents calculated for work trips. It should be emphasized that these values assume random variations in the characteristics of the third mode.

Table 5. Regression coefficients, standard errors, and t-values of car-other work trips to CBD.

	Probit Analysis						Logit Analysis				
Equation	Constant	ΔC	ΔT	Income	Distance	-2lnλ[a]	Constant	ΔC	ΔT	Income	Distance
Coefficient											
1	-0.019	-0.0033				12	-0.023	-0.0054			
2	-0.56		-0.017			75	-0.90		-0.027		
3	-1.1			0.086×10^{-3}		42	-1.7			0.14×10^{-3}	
4	-0.085				0.052	108	-1.4				0.086
5	-0.36	-0.0018	-0.016			79	-0.57	-0.0030	-0.026		
6	-0.87	-0.0036	-0.014	0.091×10^{-3}		120	-1.4	-0.0060	-0.024	0.15×10^{-3}	
7	-0.39	-0.0062	-0.012		0.060	199	-0.64	-0.010	-0.020		0.099
8	-0.67	-0.0068	-0.012	0.051×10^{-3}	0.054	211	-1.1	-0.011	-0.019	0.085×10^{-3}	0.089
Standard Error											
1	0.11	0.00097					0.18	0.0016			
2	0.035		0.0020				0.058		0.0032		
3	0.11			0.013×10^{-3}			0.18			0.022×10^{-3}	
4	0.054				0.0051		0.092				0.0086
5	0.12	0.00099	0.0020				0.19	0.0016	0.0033		
6	0.14	0.0010	0.0020	0.014×10^{-3}			0.23	0.0017	0.0033	0.023×10^{-3}	
7	0.12	0.0011	0.0021		0.0055		0.19	0.0018	0.0034		0.0094
8	0.15	0.0011	0.0021	0.015×10^{-3}	0.0058		0.24	0.0018	0.0034	0.024×10^{-3}	0.0097
t-Value											
1	0.2	3					0.1	3			
2	16		9				16		8		
3	10			6			9			6	
4	16				10		15				10
5	3	2	8				3	2	8		
6	6	4	7	6			6	4	7	6	
7	3	6	6		11		3	6	6		11
8	5	6	6	3	9		5	6	6	3	9

[a] Values are the same for logit and probit analysis.

Table 6. Regression coefficients, standard errors, and t-values of car-rail nonwork trips to CBD.

	Probit Analysis						Logit Analysis				
Equation	Constant	ΔC	ΔT	Income	Distance	-2lnλ[a]	Constant	ΔC	ΔT	Income	Distance
Coefficient											
1	2.3	-0.014				53	3.8	-0.024			
2	0.66		-0.021			37	1.1		-0.058		
3	0.60			0.077×10^{-4}		0.3	0.98			0.12×10^{-4}	
4	0.67				-0.00083	0.1	1.1				-0.0013
5	2.0	-0.012	-0.015			68	3.2	-0.019	-0.034		
6	1.6	-0.011	-0.020	0.31×10^{-4}		73	2.5	-0.018	-0.042	0.70×10^{-4}	
7	1.8	-0.012	-0.019		0.013	72	3.1	-0.020	-0.037		0.029
8	1.6	-0.011	-0.020	0.23×10^{-4}	0.0052	73	2.6	-0.018	-0.042	0.54×10^{-4}	0.011
Standard Error											
1	0.24	0.0021					0.41	0.0035			
2	0.050		0.0035				0.084		0.0087		
3	0.14			0.16×10^{-4}			0.23			0.27×10^{-4}	
4	0.076				0.0067		0.12				0.011
5	0.25	0.0022	0.0037				0.45	0.0039	0.0091		
6	0.30	0.0023	0.0046	0.14×10^{-4}			0.51	0.0037	0.0083	0.25×10^{-4}	
7	0.26	0.0022	0.0043		0.0069		0.43	0.0037	0.0077		0.012
8	0.3	0.0023	0.0046	0.20×10^{-4}	0.0098		0.5	0.0038	0.0083	0.34×10^{-4}	0.016
t-Value											
1	9	7					9	7			
2	13		6				13		7		
3	4			0.5			4			0.5	
4	9				0.1		9				0.1
5	8	5	4				7	5	4		
6	5	5	4	2			5	5	5	3	
7	7	5	4		2		7	5	5		2
8	5	5	4	1	0.5		5	5	5	1.6	0.7

[a] Values are the same for logit and probit analysis.

Car-Other Choice—The coefficients in the analysis of the car-other choice (Table 8) are significantly different from 0 at the 0.98 level generally, and their signs are all as expected.

The effect on modal choice of a change in ΔC is larger for the typical nonwork traveler than for the typical commuter, the same pattern as for the 2 specific choices (Table 3). Again, as for work trips, the effect of ΔC tends to be the same for the typical pleasure trip, irrespective of the modal choice faced. The effects of distance traveled and income tend to be the same for all choices and both purposes for the typical traveler facing that choice. The effect of changes in ΔT were not captured for this choice. As a result, it was impossible to calculate the marginal value of time.

The calculated marginal value of comfort is approximately 95 cents, less than for each specific modal choice as expected from the sample selection procedure. It is larger for nonwork trips than for work trips with the same choice.

Trip Analysis Summary

The results of the analysis of modal choice of trips to the CBD are plausible and stable: The coefficients are significantly different from 0 generally, the exceptions are understandable, and the values of the likelihood ratio test ($-2\ln\lambda$) confirm these results.

The relative sizes of the coefficients between car-rail and car-bus choices and between purposes are explainable: The coefficients of ΔC and income are smaller for work than for nonwork trips, the coefficients of ΔT are larger for work than for nonwork trips, and the coefficients of distance are smaller for the car-rail choice than for the car-bus choice and larger for work trips than for nonwork trips.

The smaller sizes of the coefficients of ΔC and of income for work trips than for nonwork trips indicate demand is less price and income elastic for work trips than for nonwork trips for a given modal split. Intuitively, habit may be a more important ingredient in choice of mode for the former than for the latter in the sense that once a modal decision has been made it probably is not reconsidered unless there is a drastic change in circumstances. In contrast, the decision may be reconsidered for each nonroutine trip. In addition, even the casual traveler is likely to be aware of income and travel costs. The converse is true for factors other than cost, for example, comfort, convenience, and time savings. Those factors are more difficult to evaluate on an a priori basis, and that may explain their apparently smaller influence on nonwork trips.

The effect of distance is not significant for the car-rail choice. For the car-bus choice, the effect of distance is larger for work trips than for nonwork trips. Train and car modes have more nearly equal comfort than do bus and car modes. Therefore, as distance increases, the relative importance of comfort increases more rapidly for car-bus than for car-rail for a given modal split. Similarly, because line-haul comfort is one of the modal characteristics that is more difficult for casual travelers to investigate, the effect of distance as a proxy for comfort is less for nonwork or infrequent trips than for work trips.

The fact that the coefficients of distance and income for the car-rail choice are not significantly different from 0 at the 0.98 level was unexpected. It could be due to the inclusion of 2 submodes, the subway or elevated and the suburban railroad, in the one rail mode. That may be inappropriate data aggregation because those 2 modes have different service characteristics with respect to scheduling and comfort and serve different geographic markets that tend to be correlated with both distance and income. Therefore, the small sizes of the coefficients of income and distance may be due to an incorrect combination of submodes and not to an actual smaller effect on modal choice of distance and income.

The relative sizes of the coefficients of ΔC and ΔT were checked through calculations of the marginal value of time for the typical traveler faced with the particular choice and trip purpose. The values are reasonable, based on other similar calculations, and vary in the expected directions. The largest calculated value is for the typical commuter faced with the car-rail choice. The values, in dollars/hour, are as follows:

Table 7. Regression coefficients, standard errors, and t-values of car-bus nonwork trips to CBD.

	Probit Analysis						Logit Analysis				
Equation	Constant	ΔC	ΔT	Income	Distance	-2lnλ[a]	Constant	ΔC	ΔT	Income	Distance
Coefficient											
1	0.28	-0.0011				0.8	0.45	-0.0018			
2	-0.057		-0.013			30	-0.092		-0.021		
3	-0.91			0.14×10^{-3}		44	-1.5			0.23×10^{-3}	
4	-0.31				0.069	58	-0.50				0.11
5	0.16	-0.0021	-0.014			32	0.25	-0.0034	-0.022		
6	-0.55	-0.0044	-0.0089	0.14×10^{-3}		64	-0.90	-0.0071	-0.015	0.22×10^{-3}	
7	0.39	-0.0086	-0.0033		0.092	89	0.64	-0.014	-0.0054		0.15
8	-0.11	-0.0091	-0.0019	0.091×10^{-3}	0.077	102	-0.17	-0.015	-0.0033	0.15×10^{-3}	0.12
Standard Error											
1	0.15	0.0014					0.24	0.0022			
2	0.056		0.0024				0.090		0.0039		
3	0.17			0.022×10^{-3}			0.28			0.036×10^{-3}	
4	0.075				0.0095		0.12				0.015
5	0.15	0.0014	0.0025				0.25	0.0023	0.0040		
6	0.20	0.0013	0.0026	0.024×10^{-3}			0.32	0.0024	0.0042	0.040×10^{-3}	
7	0.16	0.0017	0.0029		0.013		0.26	0.0027	0.0046		0.021
8	0.21	0.0017	0.0029	0.026×10^{-3}	0.013		0.34	0.0027	0.0047	0.042×10^{-3}	0.021
t-Value											
1	2	0.8					2	0.8			
2	1		5				1		5		
3	5			6			5			6	
4	4				7		4				7
5	1	1	5				1	1	5		
6	3	3	3	6			3	3	3	6	
7	2	5	1		7		2	5	1		7
8	0.5	5	0.7	4	6		0.5	5	0.7	4	6

[a] Values are the same for logit and probit analysis.

Table 8. Regression coefficients, standard errors, and t-values of car-other nonwork trips to CBD.

	Probit Analysis						Logit Analysis				
Equation	Constant	ΔC	ΔT	Income	Distance	-2lnλ[a]	Constant	ΔC	ΔT	Income	Distance
1	0.55	-0.0056				18	0.88	-0.0090			
2	-0.14		-0.0095			13	-0.22		-0.015		
3	-0.73			0.89×10^{-4}		24	-1.2			1.4×10^{-4}	
4	-0.36				0.042	34	-0.59				0.068
5	0.41	-0.0050	-0.0081			28	0.66	-0.0081	-0.013		
6	-0.15	-0.0070	-0.0049	1.1×10^{-4}		58	-0.26	-0.011	-0.0083	1.7×10^{-4}	
7	0.50	-0.0096	-0.0014		0.062	80	0.80	-0.015	-0.0024		0.10
8	0.13	-0.010	-0.00058	0.66×10^{-4}	0.051	90	0.19	-0.016	-0.0013	1.1×10^{-4}	0.082
Standard Error											
1	0.15	0.0013					0.23	0.0021			
2	0.043		0.0026				0.069		0.0043		
3	0.14			0.18×10^{-4}			0.23			0.30×10^{-4}	
4	0.066				0.0075		0.11				0.012
5	0.15	0.0013	0.0027				0.24	0.0021	0.0043		
6	0.18	0.0014	0.0027	0.19×10^{-4}			0.30	0.0022	0.0045	0.32×10^{-4}	
7	0.15	0.0015	0.0029		0.0089		0.25	0.0024	0.0046		0.015
8	0.19	0.0015	0.0029	0.21×10^{-4}	0.0093		0.3	0.0024	0.0047	0.34×10^{-4}	0.015
t-Value											
1	4	4					4	4			
2	3		4				3		4		
3	5			5			5			5	
4	6				6		6				6
5	3	4	3				3	4	3		
6	0.8	5	1.8	5			0.9	5	1.8	5	
7	3	6	0.5		7		3	6	0.5		7
8	0.7	7	0.2	3	5		0.6	7	0.3	3	5

[a] Values are the same for logit and probit analysis.

Choice	Work	Nonwork
Car-rail	2.30	1.10
Car-bus	0.70	
Car-other	1.15	

The value of the initial modal preference is due to factors such as costs of information, reliability of the mode, frequency of departure, and, in general, the relative comfort and convenience levels of the modes. The values (in dollars) attached to these factors are as follows:

Choice	Work	Nonwork
Car-rail	1.10	1.70
Car-bus	0.80	1.20
Car-other	0.35	0.95

The calculated value of this initial preference for the specific modes changes generally in the expected directions. It is larger for the car-rail choice because the rail mode is generally less convenient than the bus mode (stations are farther apart, and trains depart less frequently). It is lower for the work purpose because public transit is generally oriented toward the commuter with respect to, for example, scheduling and costs. In addition, costs of information are lower for frequent trips than for infrequent trips. The values for nonwork trips are less stable, but again all favor the automobile mode. The low calculated value for the car-other choice in relation to the values for the specific modal choices is due to the different methods of weighting the specific modal choices and the combination other choice. For the specific choices, trips by the third mode were ignored. In the combination mode, all trips were included, but travel times and costs were weighted averages.

MODEL IMPLICATIONS AND CONCLUSIONS

The models in this study were designed for a dual purpose: to be part of the UTP package of the Chicago region and to be used as regional planning and policy evaluation tools by themselves. Those aims imposed various restrictions on the models: The trip origins had to cover the entire Chicago region, and the form of the data had to be consistent with the rest of the UTP package. Subject to those restrictions, the models were developed by using methods previously employed in behavioral and disaggregated analysis.

There are 2 basic implications. The first is that the development of an interchange modal-split model from a disaggregate modal-choice model is feasible and viable. The independent variables are sufficiently general so that the models may well be generalized to other cities and times. The second is that, given these models, the implications of certain changes in regional plans and policies can be estimated. Among these plans and policies are the introduction of a new transit facility or highway, changes in pricing policies for all modes, and changes in transfer policies and scheduling on public transit.

For example, the effect on modal choice of the introduction of a new transit facility depends on the characteristics of that system, e.g., whether it is a bus or rail line and what the transit travel times and costs are compared with those of the automobile. The effect on modal choice of a change in relative travel time can be estimated by using the results of this analysis. If a new rail line downtown were introduced and decreased rail travel time by approximately 10 min; if the origin zone were typical with respect to income, distance, and bus use to the CBD; and if there were no initial travel time advantage for either the automobile or rail mode, then rail ridership would increase by approximately 10 percentage points for work trips (from a modal split of 0.50 to one of 0.60) and by approximately 7 percentage points for nonwork trips (from 0.25 to 0.32). If, under the same conditions, the new transit route considered were a bus route and if the initial time advantage were 10 min in favor of the car mode, then a 10-min decrease in bus travel time would induce an increase in bus ridership of only 3 percentage points for work trips (from 0.54 to 0.57) and of approximately 8 percentage points for nonwork trips (from 0.34 to 0.42).

If, instead of reducing transit travel time, automobile travel time were reduced through, for example, the synchronization of traffic lights, wider car lanes, or a better or new road, trips would be diverted from all transit facilities. If the initial situation of the travelers is about what the average situation was in Chicago in 1956 and if the automobile mode had an initial advantage of approximately 10 min, then a decrease of 10 min in automobile travel time would induce a decrease in transit ridership of approximately 5 percentage points for work trips (from 0.66 to 0.61).

The effect on modal choice of changes in certain policies can also be estimated by using the results of this analysis. If a tax imposed on parking lots and garages in the CBD resulted in a flat increase in parking fees of 40 cents (or 20 cents attributable to each direction) and if the average initial cost advantage of the transit mode were $1.00, then transit ridership would increase by approximately 5 percentage points for work trips (from 0.63 to 0.68) and by approximately 8 percentage points for nonwork trips (from 0.50 to 0.58). If the tax resulted in a flat increase in parking fees of $1.00 (or 50 cents each way, starting from the same initial conditions as before), then transit ridership would increase by approximately 11 percentage points for work trips (from 0.63 to 0.74) and by approximately 19 percentage points for nonwork trips (from 0.50 to 0.69). If there were a further increase of parking fees of $1.00 (for a total of $2.00 or $1.00 each way), transit ridership would increase by only 9 percentage points for work trips (from 0.74 to 0.83) and by 15 percentage points for nonwork trips (from 0.69 to 0.84). This result—as differences (in cost) become more extreme, additional changes have a smaller effect on modal choice—is a characteristic of models using functions that yield S curves.

The effect on modal choice of a change in transfer policy can also be estimated by using the results of this analysis. If transfers within the public transit mode were facilitated by schedule changes, travel time by transit would decrease. If schedules were modified so as to decrease waiting times between the suburban railroad and the connecting distributor bus by about 5 min for the average Chicago traveler and if there were no initial time advantage for either mode, then rail ridership would increase by approximately 5 percentage points for work trips (from 0.50 to 0.55) and by approximately 3 percentage points for nonwork trips (from 0.25 to 0.28).

As suburbanization increases, it might be desirable to encourage a particular modal split. These models could be used to ascertain pricing strategies that would tend to produce the desired division. For example, if travel time by car and transit were the same, then a 50 percent modal split of work trips to the CBD would be induced by a 50-cent travel cost advantage each way for the transit mode.

These are just a few examples of types of policy and planning questions that these models could help evaluate. The response of modal choice to changes in travel times and costs depends on the initial conditions and on the extent to which the factors are varied. The reaction is strongest near the 50-50 modal-split level and decreases as the split changes in either direction. Modal-choice behavior does not change dramatically in response to relatively small changes in times and costs.

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