ideas to the formulation of strategies and the organization of the study; to John Hoekwater of the Project Bureau for Integrated Transport Studies for his many ideas and his great experience; and to Erik Mackinlay of the project studies department, Ministry of Transport and Public Works, for his careful review of the paper. Its contents, and in particular its conclusions, are my thoughts and not the opinions of my employer. Copies of reports mentioned in the reference section may be obtained by writing to me.

REFERENCES

1. Computation Research and Development. SIGMO Models: Aggregate Validation Report. Project Bureau, Ministry of Transport and Public Works, the Hague, Netherlands, 1979.
2. I. Illich. Energie et Equité. Editions du Seuil, Paris, 1973.
3. Report on the Study of Traffic and Transport Strategy in Greater Amsterdam. Project Bureau, Ministry of Transport and Public Works, the Hague, Netherlands, Jan. 1975.
4. A.G. Wilson, A.F. Hawkins, G.J. Hill, and D.J. Wagon. Calibration and Testing of the SELNEC Transport Model. In Regional Studies, Volume 3, Pergamon Press, New York, 1969, pp. 337-350.
5. Supplementary Licensing Project Report. Computation Research and Development, London, 1975.
6. A.I.J.M. van der Hoorn and J. Vogelaar. SIGMO: Disaggregate Models for the Amsterdam Conurbation. In Transportation Models: Proc., Summer Annual Meeting, Planning and Transport Research and Computation Co., London, England, 1978, pp. 87-102.
7. SIGMO Study Reports, Parts 1-4. Project Bureau, Ministry of Transport and Public Works, the Hague, Netherlands, 1977.
8. A. Rühl, A. Daly, and G.G. Dobson. The Use of Disaggregate Models for Railway Investment Decisions in Holland. In Transportation Models: Proc., Summer Annual Meeting, Planning and Transport Research and Computation Co., London, England, 1977, pp. 293-306.
9. Ring Rail Study: Model Validation Report. Computation Research and Development, London, 1978.
10. SIGMO Study Report, Part 3: Home-Based Work Trips. Project Bureau, Ministry of Transport and Public Works, the Hague, Netherlands, 1977.
11. SIGMO Study Report, Part 6 (SIGMAT). Ministry of Transport and Public Works, the Hague, Netherlands (in preparation).

Use of Incremental Form of Logit Models in Demand Analysis

ASHOK KUMAR

Many transportation systems management policies are geared toward making minor changes in the level of service (LOS) provided by transportation networks in an urban area. Estimation of changes in travel demand is usually prerequisite to assessing the costs and benefits associated with such policies. The pivot-point technique, which uses the incremental logit model, is especially suited for this type of analysis. This procedure predicts revised travel behavior based on existing travel behavior and changes in LOS experienced by a trip maker. The major advantage of this procedure is that no knowledge of detailed existing LOS data on all relevant alternatives available to a trip maker is required. Only estimates of existing market shares and proposed changes in modal disutilities are necessary. Based on the values of the coefficients of travel time and travel cost reported in transportation literature, default values of the coefficients of in-vehicle travel time, out-of-vehicle travel time, and out-of-pocket travel cost have been suggested. These coefficients can then be used to calculate the changes in modal disutilities due to changes in travel time, travel cost, or both. The use of this technique is discussed by using a case study.

More and more, transportation planners are being asked to consider low-capital short-range transportation system management (TSM) solutions prior to justifying transportation improvements such as fixed-guideway transit facilities and limited-access highways in an urban travel corridor to alleviate traffic congestion. Some of the management strategies for shifting motorists to public transportation modes involve consideration of changes in headway, routing, and fare structure; preferential treatment; signal preemption; and express service and route extensions. Operating strategies for discouraging the use of the automobile on the highway system may include consideration of preferential treatment for high-occupancy vehicles and, at certain locations, parking restrictions, parking-fee surcharges, or both. Such strategies should also be analyzed in the preparation of a state implementation plan for the attainment of air-quality standards and of an energy contingency plan. Transportation analysts are invariably asked to assess the impacts associated with such changes. Assessing changes in travel demand for the subject mode and competing modes is usually prerequisite to estimating impacts on energy consumption, air and noise pollution, fare-box revenues, and operating expenses.

It is usually difficult to estimate the changes in travel demand by using the classical Urban Transportation Modeling System (UTMS). Many binary mode-choice modeling techniques developed during the 1960s (1) have proved to be ineffective in computing the changes in travel demand. These techniques were primarily designed for system-level transportation and land-use studies and could not easily split the travel demand among the several competing transit and automobile mode choices usually present in a large metropolitan area. Since these models cannot adequately simulate the equilibrium flows along competing transit routes, changes in travel demand due to minor changes in level of service (LOS) cannot be accurately estimated.

Multinomial logit models (2,3) enable analysis of multiple transit and highway options simultaneously. In addition, the incremental form of a multinomial logit model is especially suited for analyzing the shifts in market shares of competing modes if the LOS for one of the modes is changed. The following sections describe the structure and application of an incremental logit model in estimating changes in travel demand due to LOS changes.

INCREMENTAL LOGIT MODEL

This procedure predicts revised travel behavior based on existing travel behavior and changes in LOS (such as travel time and travel cost) experienced by a trip maker. The major advantage of this procedure is that no knowledge of detailed existing LOS data [such as parking fees paid in the central business district (CBD) and travel times] on all alternatives available to a trip maker is required. Only existing probabilities (market shares) and proposed changes in the LOS are necessary. The incremental form of the logit model is used to pivot about an existing situation. The use of this technique in transportation systems analysis has been pioneered by the Rand Corporation (4) and by Cambridge Systematics (5). This procedure has also been discussed in a recent National Cooperative Highway Research Program report (6).

The incremental form of the logit model (5) is expressed

$$P^{\wedge}(i:A) = [P(i:A)\exp(\Delta U_i)] \Big/ \left[\sum_{m \in A} P(m:A)\exp(\Delta U_m)\right] \quad (1)$$

where

$P^{\wedge}(i:A)$ = revised market share of alternative i out of A possible alternatives available to a trip maker,
$P(i:A)$ = original market share of alternative i,
ΔU_i = change in disutility (travel time, travel cost, or both), and
m = summation index.

For example, assume that for a given community there are the following three modes available to commute to the CBD: express bus, rail rapid transit, and automobile. The existing market shares of these modes are expressed P_{bus}, P_{rail}, and P_{auto}. Further, assume that the travel time and travel cost associated with these modes are changed so that the changes in disutility associated with these modes are given by ΔU_{bus}, ΔU_{rail}, and ΔU_{auto}.

By using the incremental form of the logit model, the revised market shares are then expressed as follows:

$$P_{bus}{}^{\wedge} = P_{bus}\exp(\Delta U_{bus}) \div [P_{bus}\exp(\Delta U_{bus}) + P_{rail}\exp(\Delta U_{rail}) + P_{auto}\exp(\Delta U_{auto})] \quad (2a)$$

$$P_{rail}{}^{\wedge} = P_{rail}\exp(\Delta U_{rail}) \div [P_{bus}\exp(\Delta U_{bus}) + P_{rail}\exp(\Delta U_{rail}) + P_{auto}\exp(\Delta U_{auto})] \quad (2b)$$

$$P_{auto}{}^{\wedge} = P_{auto}\exp(\Delta U_{auto}) \div [P_{bus}\exp(\Delta U_{bus}) + P_{rail}\exp(\Delta U_{rail}) + P_{auto}\exp(\Delta U_{auto})] \quad (2c)$$

It is customary to express the disutility associated with any mode as a weighted combination of travel time and travel cost associated with that mode:

$$U_i = A_1 * time_i + A_2 * cost_i \quad (3)$$

where

U_i = disutility associated with mode i to travel to any specific destination j,
$time_i$ = travel time associated with mode i to travel to destination j,
$cost_i$ = travel cost associated with mode i to travel to destination j, and
A_1, A_2 = weights associated with travel time and travel cost that show their relative importance.

Travel-behavior studies also indicate that time spent walking and waiting (out-of-vehicle time) is perceived differently from time spent traveling (in-vehicle time). In addition, trip makers who have different socioeconomic characteristics (income, occupation, etc.) attach different values to travel-time and travel-cost coefficients. Therefore, Equation 3 is modified and rewritten as follows:

$$U_i = A_0 * [\text{out-of-vehicle time}] + A_1 * [\text{in-vehicle travel time}] + A_2 * [\text{out-of-pocket travel cost}] + A_3 * \text{income} \quad (4a)$$

or

$$U_i = A_0 * [\text{out-of-vehicle time}] + A_1 [\text{in-vehicle travel time}] + (A_2/\text{income}) * [\text{out-of-pocket cost}] \quad (4b)$$

It should be noted that these are just a few of the mathematical forms of utility expression. Other forms of utility expression used in travel-demand-modeling studies are discussed in a publication prepared by the Federal Highway Administration (FHWA) (7).

The changes in the disutility expression due to change in travel time, travel cost, or both by using Equation 4a can be expressed as follows:

$$\Delta U_i = A_0 * [\text{change in out-of-vehicle time}] + A_1 * [\text{change in in-vehicle travel time}] + A_2 * [\text{change in out-of-pocket travel cost}] \quad (5)$$

In order to use the incremental form of the logit model (Equation 1), one must specify the existing market shares; the changes in travel time, travel cost, or both; and weight coefficients A_0, A_1, and A_2. Existing market shares can usually be approximated by first estimating total person trips between the origin-destination (O-D) pair in question and then by using the results of recent on-board surveys, base-year O-D surveys, U.S. Bureau of Census journey-to-work data (8), and all other data sources available for a study area on mode choice. Changes in travel time, travel cost, or both can be easily related to the systems management policy under consideration. If multinomial logit models have been calibrated for the study area under consideration, values of weight coefficients A_0, A_1, and A_2 can readily be substituted in Equation 1. However, if the calibrated models are not available, it becomes necessary to borrow these values from other study areas. For several metropolitan areas, the values of the coefficients for in-vehicle travel time, out-of-vehicle travel time, and out-of-pocket cost have already been estimated. Table 1 shows these values for the mode-choice models calibrated for the metropolitan areas of San Diego (2), Minneapolis and St. Paul (Twin Cities) (9), Washington, D.C. (10), and Chicago (11). The values vary somewhat depending on other socioeconomic variables used in formulating the utility expressions for these areas. The utility expressions used for calibrating mode-choice models for San Diego, Twin Cities, and Chicago are similar

Table 1. Coefficients for in-vehicle and out-of-vehicle travel times and out-of-pocket cost in logit models.

Study	In-Vehicle Travel Time	Out-of-Vehicle Travel Time	Out-of-Pocket Cost
Home-to-Work Trips			
San Diego	0.0563	0.0916	0.0106
Twin Cities	0.032	0.044	0.014
Washington, D.C.	0.0308	0.320 ÷ travel distance (miles)	57.6 ÷ annual household income ($)
Chicago	0.040	NA	0.010
Home-to-Nonwork Trips			
Twin Cities	0.007	0.018	0.011
Chicago	0.0054	NA	0.014

to Equation 4a, whereas the utility expressions employed in calibrating mode-choice models by using Washington, D.C., travel-survey data (10) are much more complex. Variables such as the number of automobiles per licensed driver in the household, the household income after mandatory expenses, the dummy variable that indicates whether the worker is a major breadwinner in the household, the dummy variable that indicates whether the worker is a civilian employee of the federal government, the number of workers in the household, and the employment density at the work zone have been used in specifying the utility expressions for work-trip mode choice. Although these causal variables improve the overall statistical predictive ability of mode-choice models, stratification of trips by such detailed socioeconomic characteristics usually cannot be easily achieved by using conventional transportation-planning data. Therefore, if it becomes necessary to borrow the values of logit coefficients from other studies, it is suggested that the analyst assume that existing choice probabilities (market shares) for modes under consideration are governed by utility expressions such as Equation 4a. Transferability of individual choice models to urban areas other than the one used for model calibration has been reported (2,12).

Based on the values shown in Table 1 and limited validation performed for the case study to be presented later, the following default values of the coefficients for in-vehicle travel time, out-of-vehicle travel time, and out-of-pocket cost are recommended:

Variable	Home-to-Work Trips	Home-to-Nonwork Trips
In-vehicle travel time	0.032	0.007
Out-of-vehicle travel time	0.052	0.018
Out-of-pocket travel cost	0.010	0.010

Aggregation and Market Segmentation

Prior to the application of Equation 1 to calculate revised market shares of competing modes, it is necessary to specify the assumptions related to aggregation and market segmentation. Note that, although Equation 1 actually holds for an individual trip maker, for planning purposes the choice probabilities should be estimated by traffic zones, political units, or both. The use of Equation 1 for a group of individuals rather than for a single individual does not cause bias provided the group of individuals has

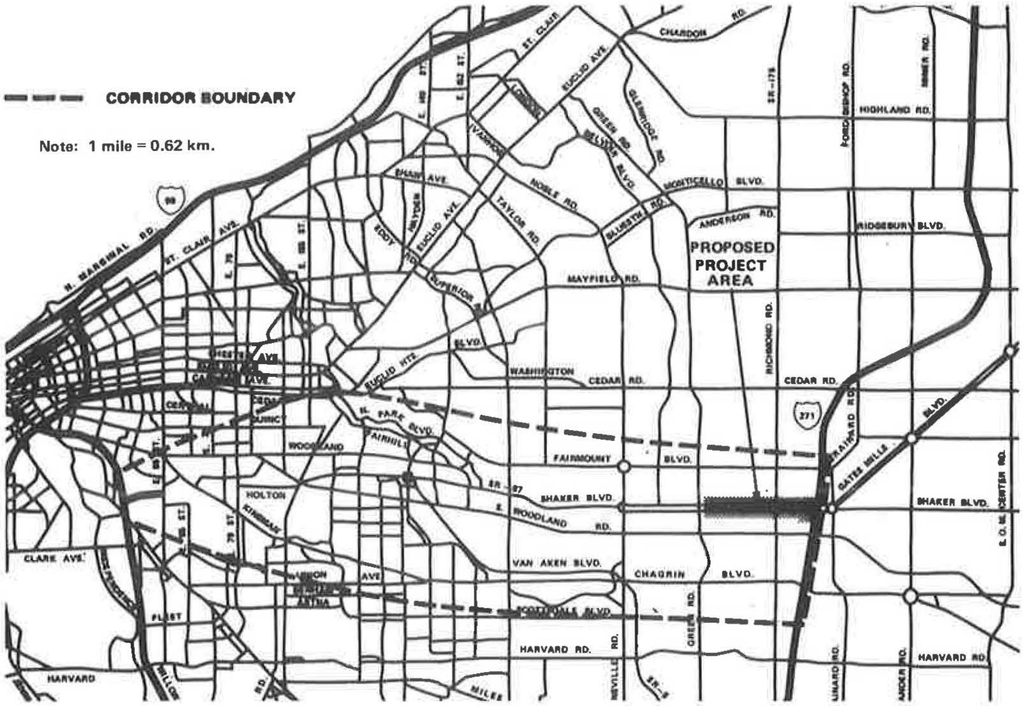
1. Identical sets of choices available to complete the journey, i.e., choice of bus, rail, and automobile;
2. Identical values of travel-time and travel-cost components; and
3. Identical socioeconomic characteristics.

Several schemes to facilitate aggregation and market segmentation have been proposed by Talvitie (13) and by Koppelman (14). The simplest of the aggregation techniques is the naive approach, which assumes that the choice probabilities computed at the mean values of the explanatory variables in the utility expression represent average choice probabilities for that group. In other words, by using the naive approach, the aggregate mode splits can be computed for an O-D pair by simply substituting in the utility expressions zonal means of socioeconomic data (such as mean household income and mean zonal parking fee) and zone-to-zone time and distance skims obtained by using standard Urban Transportation Planning System (UTPS) and FHWA PLANPAC software. However, due to the nonlinear relationship between choice probability and model disutility implied in the logit formulation, average choice probability computed by using the naive approach may be significantly biased. To circumvent this problem, Talvitie (13) suggested using the approximate aggregate utility function obtained by using a Taylor-series expansion about the mean values of the explanatory variables in the utility expression and truncating the series after variances and covariances of the distribution of independent variables have been incorporated. By using this approach, it is possible to derive the aggregate form of the incremental logit model. However, computation of variances of variables such as walking distance to the transit stop, parking fees, and other discrete socioeconomic variables used in the utility expression usually poses a problem and therefore this procedure is difficult to use.

Koppelman and Ben-Akiva (15) have suggested a classification approach to reduce the bias introduced in the naive approach. In this procedure the decision makers are classified into a set of relatively homogeneous groups by virtue of choice-set availability, socioeconomic characteristics, LOS experience, or all three characteristics. For example, trip makers can be classified by availability of automobile and transit mode or modes, income, distance to the transit stops, or all three. For each group, the mean choice probabilities are computed by using the naive approach and aggregate probability is computed as the weighted sum of group probabilities. Usually, in practical planning applications, determination of homogeneous groups with respect to choice-set availability, socioeconomic characteristics, and LOS becomes a formidable task, especially if the utility expressions use several socioeconomic variables, e.g., the utility expressions used for the U.S. Department of Energy's State Energy Conservation Program (5). Therefore, in practice, groups are determined either on the basis of choice-set availability or LOS experience. If the classification approach is the aggregation procedure chosen, it appears most prudent to calibrate the mode-choice models by using simpler utility expressions (for example, Equations 4a or 4b) and to determine choice-set availability on the basis of automobile availability and dichotomized distance to the transit stop (that is, acceptable versus unacceptable walking distances to the transit stop). I will discuss issues related to determination of automobile availability again later in this paper.

Two other approaches used in aggregate predictions from disaggregate models are the

Figure 1. Southern Heights Corridor.



sample-enumeration and pseudosample-enumeration procedures. In the sample-enumeration technique, before-and-after choice probabilities are computed after the utility expressions have been modified to reflect the policy under consideration for a sample of households for which detailed socioeconomic, LOS, and choice-set availability data exist. Calculated changes in the choice probabilities of the sample are then used to draw inferences about the entire population. Examples of this approach can be found in the work of Cambridge Systematics (5,16). The sample-enumeration procedure can provide accurate predictions; however, this procedure is not feasible for TSM-type project-level planning due to the unavailability of special household survey samples from the project market area. Use of this technique also relies on the availability of and the familiarity with special computer programs designed for this purpose (16). The pseudosample-enumeration technique relies on the synthetic household samples constructed by randomly sampling from the postulated distributions of LOS and socioeconomic data. These synthetic samples are then used to compute before-and-after choice probabilities and to draw inferences about the proposed policy. Examples of the use of the pseudosample-enumeration technique to perform aggregation may be seen in several reports (16,17). Like the sample-enumeration technique, this procedure is also tied to the use of special computer programs.

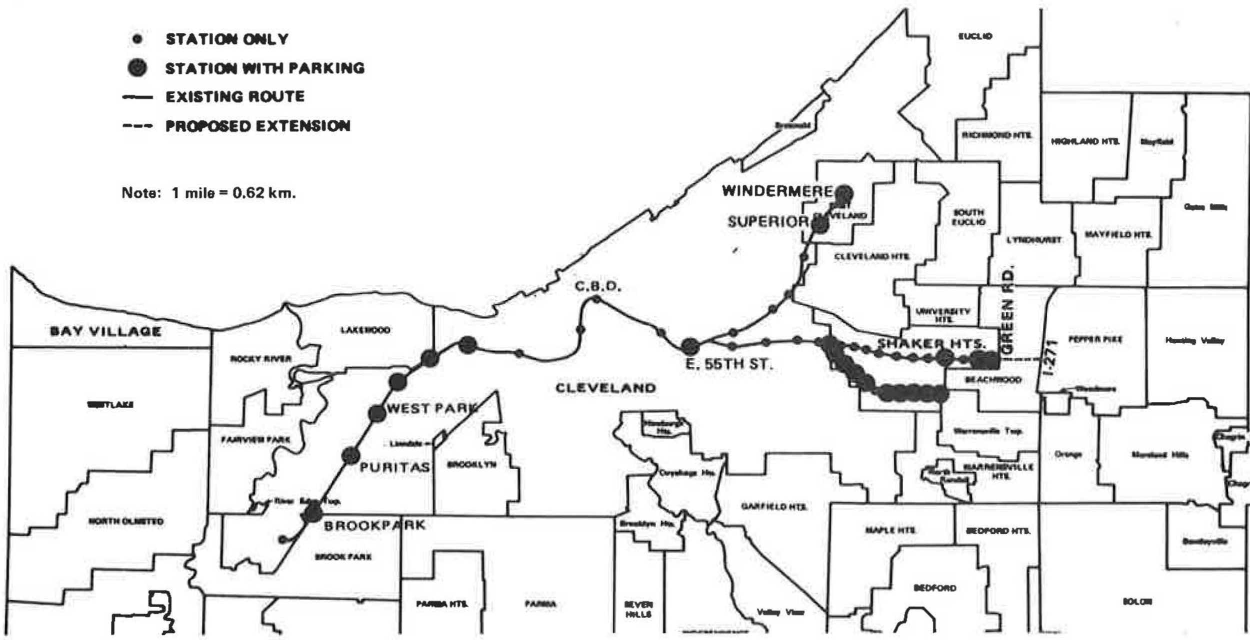
Applicability of the aggregation techniques described above is dictated to a great extent by the availability of transportation-planning data (especially the type of data that were collected during the on-board surveys), the analytical capabilities of the analyst, and the other components of the modeling system developed by the Metropolitan Transportation Planning Study. Invariably, the naive approach adjusted for the choice-set availability is the most practical way to estimate aggregate market shares. It has been further shown by Koppelman (18) that changes in market shares estimated by using the pivot-point procedure tend to have minimal aggregation bias.

A case study presented below further illustrates the application of incremental logit models in transportation planning.

Case Study

Figure 1 shows the major freeway and arterial highway network that provides access to the Cleveland CBD in the eastern half of the Cleveland metropolitan area. It also shows the general corridor location of the proposed Interstate 290. However, due to anticipated adverse social, economic, and environmental impacts of the freeway construction, project planning for I-290 has been dropped. Figure 2 shows the rail facilities available in the metropolitan area. An extensive rail network is also available to provide line-haul and feeder service within Cuyahoga County. Many planning studies have proposed the easterly extension of the Shaker Green Line from its current terminus at the Shaker Green--West Green Road stop to the I-271 overpass at Shaker Boulevard (Figure 2). The proposed project is about 2.25 km (1.4 miles) long and can be accommodated within the median of Shaker Boulevard (Figure 1). Besides extending the Shaker Green Line, a proposal has also been made to construct a new parking lot in the vicinity of the I-271 and Shaker Boulevard overpass and to build special ramps from I-271 to provide exclusive access to this parking facility. To discourage through traffic, automobile access between local streets and the parking facility or I-271 would not be permitted. To serve the local communities, a proposal has been made to build a station and a small parking lot at Richmond Road. A feasibility study is currently under way to determine the cost-effectiveness of this proposal along with three other alternatives, namely, do nothing, expand the existing parking lot at Green Road, and build an autoway. The autoway alternative

Figure 2. Rail transit system.



essentially involves building a new parking lot in the vicinity of Green Road and constructing a two-lane roadway within the Shaker Boulevard median to connect this new lot to I-271 by a set of exclusive-access ramps. For this alternative, also, access would not be permitted between local streets and the new parking lot, the autoway, and I-271. The method used to estimate patronage by using the incremental logit model is summarized below. Complete details of this method may be found elsewhere (19).

Patronage Estimation

Identification of Market Area

The first step in using the incremental logit model for pivot-point analysis involves identification of the O-D interchanges for which the existing market shares of different transportation modes may be altered due to the proposed LOS changes in one or more modes that serve these interchanges. Usually, results of on-board surveys and LINKUSE (computer program issued as part of FHWA PLANPAC software package in 1976) analysis can be readily used to establish the market area. For this case study, results of an on-board survey indicated that the primary use of the rail extension or alternatives by the communities in the market area would be to commute to the Cleveland CBD. For example, results indicated that 92 percent of the boardings at the Shaker Green--West Green Road stop were bound for the CBD and only 3.6 percent of the boardings were due to commuters who were going the other way. Therefore, it was decided to analyze only the home-based-work and home-based-nonwork trips from these communities to the CBD.

Determination of Existing Market Shares

After O-D interchanges that need to be analyzed have been established, the next step in the process involves determination of existing market shares of all transit and automobiles modes that serve these interchanges. This is essentially a multistep process. Results of person trip-generation and trip-distribution analyses can be used to estimate the total person trip interchanges for home-based-work and home-based-nonwork trips. To facilitate the market segmentation of trips by automobile availability, a cross-classification approach to trip generation is very useful. If automobile ownership is used as one of the stratifying variables in trip generation, trips from households with cars and without cars can be readily estimated. Examples of home-based-work and home-based-nonwork person trip-production rates as a function of automobile ownership, household size, and residential density may be found elsewhere (20). A method for estimating joint distribution of household size and automobile ownership at the zonal level to apply the production rates by using readily available zonal data such as mean household size and mean automobile ownership is also described elsewhere (21). It should be noted that the segmentation of trips by automobile availability frequently used in mode-choice analysis is not the same as stratification of trips from automobile-owning and carless households. It is possible that the automobile from automobile-owning households may not be available for trips at certain times of the day, whereas carless households may have the option of using a carpool to make trips. An empirical technique due to Wilson (22) can be used to approximate market segmentation with respect to automobile availability if the trip-generation analysis is conducted as described above.

The next step in the process is to tabulate the results of the most-recent on-board survey to estimate the number of transit trips made by means of different line-haul modes and associated access and egress modes that serve the market-segmented trip interchanges. The number of automobile trips can be estimated by subtracting the total number of transit trips from the total number of person trips. An example of such a tabulation may be seen in an earlier paper (19). For this case study, the analysis of home-to-nonwork trips posed an interesting problem. A parking-lot survey conducted at the Shaker Green--West Green Road stop indicated that this lot is about 90 percent occupied by 9:00

a.m., whereas a 1963 home O-D survey showed that about 60 percent of the nonwork person trips to the CBD are made between 9:00 a.m. and 4:00 p.m. Therefore, it became apparent that there is a latent demand for additional park-and-ride facilities. In order to determine the magnitude of this latent demand, use of parking spaces at the Brookpark, Puritas, and Westpark stops (Figure 2) was studied. The maximum occupancy of parking spaces at these stops is currently about 42 percent. Therefore, it was assumed that communities served by these stops do not experience any parking shortages during any time of the day. Results of an on-board survey showed that about 7 percent of the home-to-nonwork trips to the CBD from these communities are made by using the rapid transit and park-and-ride mode of access. Communities served by the Shaker Green--West Green Road stop showed that only 3.5 percent of the nonwork trips to the CBD were made by using the Shaker Green Line and park-and-ride mode of access. I assume that, if there were no shortage of parking space at the Shaker Green--West Green Road lot, 7 percent of the nonwork trips would have been made by using rail rapid transit; the unconstrained number of park-and-ride trips was derived by factoring the observed number of trips by 2.0. Once the number of trips along all possible modes that serve an O-D pair had been determined, aggregate market shares were calculated by dividing the modal trips by total person trips.

Determination of Changes in Modal Disutilities

Changes in modal disutilities can be calculated first by expressing the proposed policy in terms of changes in travel time and travel cost and then by multiplying these changes by the appropriate coefficient values presented earlier. For this case study, the impact on the number of boardings at the Shaker Green--West Green Road stop was analyzed for (a) possible reduction in automobile access time to the stop due to the construction of new ramps (autoway and rail-extension alternatives) and (b) possible increase in automobile operating cost due to the gasoline-price increase. Three possible scenarios for automobile operating cost increases were developed: 25, 50, and 100 percent increase in automobile operating cost per mile.

Determination of Revised Market Shares

Once the existing market shares have been estimated and changes in modal disutilities calculated, revised market shares can be obtained by using Equation 1. At times the revised market share may indicate trips on a certain mode that are not physically possible due to the supply constraint. For example, in the present case study, the do-nothing option cannot accommodate additional park-and-ride trips. However, if the pivot-point procedure is applied by assuming increase in automobile operating expense and no change in transit fare, more trips may be assigned to the Shaker Green Line than are physically possible. To avoid this situation, a shadow price can be calculated to artificially increase the disutility of the mode in which equilibrium between supply and demand has to be maintained.

For this case study, the shadow price was calculated as follows. Let $P_{rail}{}^a$, $P_{rail}{}^o$, P_{bus}, and P_{auto} be the existing market shares of rail with automobile access (park-and-ride), rail with access modes other than automobile (walk, feeder bus, kiss-and-ride), express bus, and automobile, respectively. Let ΔU_{auto} denote the change in disutility of the automobile mode. Then, by using the incremental logit model, the revised market share of rail that has the automobile access mode ($\hat{P}_{rail}{}^a$) can be expressed as follows:

$$\hat{P}_{rail}{}^a = P_{rail}{}^a/[P_{rail}{}^a + P_{rail}{}^o + P_{bus} + P_{auto}\exp(\Delta U_{auto})] \quad (6)$$

Now, if the impact of change in disutility of the automobile mode (that is, ΔU_{auto}) is such that $\hat{P}_{rail}{}^a > P_{rail}{}^a$ but it is not physically possible to satisfy this additional demand due to supply constraint, a shadow price (ΔC) can be imposed on the rail alternative that has automobile access to ensure that $\hat{P}_{rail}{}^a = P_{rail}{}^a$. The numerical value of this shadow price can be calculated by using Equation 6 as follows:

$$P_{rail}{}^a = P_{rail}{}^a\Delta C/[P_{rail}{}^a\Delta C + P_{rail}{}^o + P_{bus} + P_{auto}\exp(\Delta U_{auto})] \quad (7)$$

This expression can be rearranged to yield

$$\Delta C = [P_{rail}{}^o + P_{bus} + P_{auto}\exp(\Delta U_{auto})]/(1 - P_{rail}{}^a) \quad (8)$$

The revised market shares of rail that has access other than by automobile ($\hat{P}_{rail}{}^o$), express bus ($\hat{P}_{bus}$), and automobile ($\hat{P}_{auto}$) can be calculated by using the following equations:

$$\hat{P}_{rail}{}^o = P_{rail}{}^o/[P_{rail}{}^a\Delta C + P_{rail}{}^o + P_{bus} + P_{auto}\exp(\Delta U_{auto})] \quad (9)$$

$$\hat{P}_{bus} = P_{bus}/[P_{rail}{}^a\Delta C + P_{rail}{}^o + P_{bus} + P_{auto}\exp(\Delta U_{auto})] \quad (10)$$

$$\hat{P}_{auto} = P_{auto}\exp(\Delta U_{auto}) \div [P_{rail}{}^a\Delta C + P_{rail}{}^o + P_{bus} + P_{auto}\exp(\Delta U_{auto})] \quad (11)$$

where ΔC is first calculated by using Equation 8.

Numerical Example

For the city of Mayfield Heights, data related to home-based work trips to the CBD are as follows: total person trips to the CBD = 793, trips made by using the Shaker Green Line = 141, and trips made by using express bus = 186. Network analysis indicated that reduction in access travel time by automobile to the Shaker Green--West Green Road lot due to the construction of an autoway alternative would be 3.4 min. If the automobile operating cost per mile increases by 50 percent, change in travel cost for a trip to the CBD will be 33¢. To determine the number of new rides on the Shaker Green Line from this community, we use the following calculations:

$P_{Shaker} = 141/793 = 0.178$, $P_{bus} = 186/793 = 0.234$, $P_{auto} = 466/793 = 0.588$, $\Delta t_{Shaker} = 3.4$ min, $\Delta c_{auto} = 33¢$.

By using Equation 1 and the default values of the coefficients for in-vehicle travel time and travel cost, the revised market share of the Shaker Green Line is calculated as follows:

$$\hat{P}_{Shaker} = [0.178 \times \exp(0.032 \times 3.4)]/[0.17 \times \exp(0.032 \times 3.4) + 0.234 + 0.588 \times \exp(-0.01 \times 33)] = 0.232.$$

Therefore, new rides on the Shaker Green Line = 0.232 x 793 - 141 = 43.

Changes in market shares for home-to-nonwork trips to the CBD were analyzed in a similar manner. Changes in ridership due to non-home-based trips and destinations other than the CBD were estimated by using suitable factors for the home-based-work and nonwork trips (19).

Table 2. Projected new rides on the study alternatives.

	Assumed Automobile Operating Cost per Mile (cents)[a]			
Study Alternative	6	7.5	9	12
Do nothing	0	250	520	1126
Expand Green Road parking lot	638	1912	2888	5016
Build autoway	1224	2208	3236	5538
Extend rail line	1932	2938	3998	6370

[a]At the time of this study, the prevailing perceived out-of-pocket cost for operating the automobile was assumed to be 6¢/mile.

RESULTS

The results obtained by using pivot-point analysis and base-year (1975) market shares are summarized in Table 2.

CONCLUSION

Changes in travel demand due to changes in LOS on one or more transportation modes that serve an urban area can be readily estimated by using pivot-point analysis. This technique is much less cumbersome to use than traditional mode-split models. Many policy issues related to fare structure, headway, automobile operating cost, etc., can be quickly analyzed by using this procedure. This paper also illustrates the use of pivot-point analysis for specific project-level planning in addition to its use for the quick order-of-magnitude analyses described in the literature (5,16).

ACKNOWLEDGMENT

The preparation of this paper was financed through a grant for technical studies from the Urban Mass Transportation Administration and the Federal Highway Administration of the U.S. Department of Transportation with joint sharing in the cost by Cuyahoga, Geauga, Lake, Lorain, and Medina counties and the municipalities within them.

REFERENCES

1. M. J. Fertal, E. Weiner, A. J. Balek, and A. F. Sevin. Modal Split: Documentation of Nine Methods for Estimating Transit Usage. Bureau of Public Roads, U.S. Department of Commerce, 1967.
2. Peat, Marwick, Mitchell and Co. Implementation of the N-Dimensional Logit Model. Comprehensive Planning Organization, San Diego, CA, 1972.
3. D. McFadden. Conditional Logit Analysis of Qualitative Choice Behavior. In Frontiers in Econometrics (P. Zarembka, ed.), Academic Press, New York, 1973.
4. Rand Corporation. A Policy-Oriented Urban Transportation Model: The San Diego Version. Office of Environmental Management, County of San Diego, Santa Monica, CA, 1973.
5. Cambridge Systematics. Guidelines for Travel-Demand Analysis of Program Measures to Promote Carpools, Vanpools, and Public Transportation. U.S. Department of Energy, 1976.
6. G. V. Wickstrom and A. B. Sosslau. Travel Estimation Procedures for Quick Response to Urban Policy Issues. NCHRP, Rept. 186, 1978.
7. B. D. Spear. Application of New Travel-Demand-Forecasting Techniques to Transportation Planning. Urban Planning Division, Federal Highway Administration, U.S. Department of Transportation, 1977.
8. Census Data and Urban Transportation Planning. TRB, Special Rept. 145, 1974.
9. R. H. Pratt and Associates and DTM, Inc. Development and Calibration of Mode-Choice Models for the Twin Cities Metropolitan Council. Minneapolis, MN, 1976.
10. T. J. Atherton, J. H. Suhrbier, and W. A. Jessiman. Use of Disaggregate Travel-Demand Models to Analyze Carpooling Policy Incentives. TRB, Transportation Research Record 599, 1976, pp. 35-40.
11. M. F. Wigner. Disaggregated Modal-Choice Models of Downtown Trips in the Chicago Region. HRB, Highway Research Record 446, 1973, pp. 49-65.
12. T. J. Atherton and M. E. Ben-Akiva. Transferability and Updating of Disaggregate Travel-Demand Models. TRB, Transportation Research Record 610, 1976, pp. 12-18.
13. A. P. Talvitie. Aggregate Travel-Demand Analysis with Disaggregate or Aggregate Travel-Demand Models. Proc., Transportation Research Forum, Vol. 14, No. 1, 1973.
14. F. S. Koppelman. Methodology for Analyzing Errors in Prediction with Disaggregate Choice Models. TRB, Transportation Research Record 592, 1976, pp. 17-23.
15. F. S. Koppelman and M. E. Ben-Akiva. Aggregate Forecasting with Disaggregate Travel-Demand Models Using Normally Available Data. Presented at World Conference on Transport Research, Rotterdam, the Netherlands, 1977.
16. Cambridge Systematics. Urban Transportation Energy Conservation: Case City Applications of Analysis Methodologies, Volume 3. U.S. Department of Energy, 1978.
17. Urban Systems. Aggregation Procedure--The Monte Carlo Simulation. Northeast Ohio Areawide Coordinating Agency, Cleveland, 1978.
18. F. S. Koppelman. Guidelines for Aggregate Travel Prediction Using Disaggregate Choice Models. TRB, Transportation Research Record 610, 1976, pp. 19-24.
19. A. Kumar. Mode-Mixer Feasibility Study: Patronage Estimates. Northeast Ohio Areawide Coordinating Agency, Cleveland, 1979.
20. A. Kumar. Trip-Generation Analysis: Calibration of Trip Production Models. Northeast Ohio Areawide Coordinating Agency, Cleveland, 1980.
21. A. Kumar. Trip-Generation Analysis: Methodology for Estimating Joint Distribution of Household Size and Automobile Ownership. Northeast Ohio Areawide Coordinating Agency, Cleveland, 1980.
22. A. G. Wilson. Urban and Regional Models in Geography and Planning. Wiley, New York, 1974.