Innovative Transit Service Planning Model That Uses a Microcomputer

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Transit service planning is the process of designing appropriate services, including considerations of area coverage, integration with other transit services, and the frequency of service that can be justified economically as well as socially and politically. A simple and usable analytic model to guide management in the search for, and evaluation of, operating strategies that meet local transit service objectives is described. This analysis system is intended primarily for use on single routes or in transit corridors that include a small number of parallel or serial routes. The model system includes as basic components models of supply (system performance), demand (mode and path choice), cost, and evaluation-measure prediction. The supply-and-demand components are linked in an explicit equilibration structure to include the important interactions between transit system performance and passenger volume. Design options that can be explored with the model system include fare and headway changes, scheduling changes such as turn-backs, etc. Two major aspects of this model system are that (a) it is designed to make maximum use of readily available data and (b) it has been implemented on a microcomputer (an Apple III) in order to minimize the investment in computer resources.

Today operators of urban transit systems are in the difficult position of facing demands for improved and more widespread services on the one hand and increasingly stringent financial constraints on the other. This requires the operator to design new services very carefully and to look critically at existing services on a route-by-route basis to determine whether the level of service (LOS) being provided is economically justifiable. Whether designing new services or examining old ones, it is vital that the operator have appropriate performance measures and analytical tools to aid the operations-planning activities.

The objective of the research reported here is to develop such tools. The analysis system that results from this effort is intended primarily for use on single routes or in transit corridors that include a small number of parallel or serial routes. It is important to emphasize that the analysis system is built around interacting supply-and-demand models. Existing supply models, which represent the impacts of routing and scheduling decisions, are not sufficient in themselves because they assume fixed travel demands, while many service changes are expected to create substantial demand changes. Existing demand models reflect the impacts of service changes but generally treat LOS measures in a way that does not support effective operations planning and management. In addition, these models usually ignore relevant service measures such as on-time reliability. Linking improved supply-and-demand models together in an equilibrium structure and rationalizing their level of detail and sensitivity enables the manager or analyst to obtain policy-relevant predictions of the impacts of alternative service strategies.

A major concern of this research is to ensure that the models developed can be used easily and effectively by transit operators. This has resulted in two major decisions regarding model structure. First, the models are implemented on a microcomputer (an Apple III) in order to minimize the investment in computer resources necessary for an operator to use the models. This is a major departure from other operations-planning models such as IGTDS (1) and TNOP (2), which require large mainframe computers and sophisticated interactive graphics hardware. Although such models are powerful, they are complex in structure and require expertise not readily available to many transit operators.

The second major aspect of this model system is that it is designed to operate primarily with data normally available at most transit properties. This minimizes the data-collection costs imposed on an operator to use the system. Although there is no substitute for good data if we wish to make precise predictions of the effects of various operational changes, it is important to provide options to the operator or analyst to allow rough estimates to be obtained with little detailed data. This improves the responsiveness of the model system because it reduces the cost of specifying new alternatives to be analyzed.

OVERVIEW OF MODEL SYSTEM

The analysis system includes basic component models of supply (system performance), demand (mode and path choice), costs, and evaluation-measure prediction. The supply-and-demand components are linked in an explicit equilibration structure to include the important interactions between system performance and passenger volume. The overall organization of the model system is illustrated in Figure 1.

The service specification determines the operating cost of the system and initial values for four basic performance measures. These performance measures both influence, and are influenced by, ridership. When equilibrium values of the performance measures and ridership have been achieved, the basic evaluation measures can be predicted. These basic evaluation measures can be used simply as a list of individual measures or combined in various ways. For example, several partial cost-effectiveness measures such as operating cost per trip, operating deficit per trip, passengers per vehicle mile, etc., may be formed.

Based on these evaluation measures, the service specification can be revised if necessary and the analysis redone with the new values. Iterations of this sort can be repeated until the user (transit operator or planner) is satisfied with the evaluation measure values.

The next section of this paper provides a summary of the component models. Additional technical details on the models are contained in Turnquist and others (3,4). The other sections describe data requirements of the model system and conclusions.

COMPONENT MODELS

Supply Model

The basic structure of the supply-model system is illustrated in Figure 2. The inputs are environmental characteristics (speed limits and numbers of signalized intersections along route segments), the service specification (route length, service frequency, stop spacing, and fare), and ridership (from the demand model). Outputs are an LOS vector (including fare, in-vehicle time, access or egress time, wait time, and transfer time) to be input to the demand model, as well as estimates of vehicle hours and vehicle miles for cost estimation.

Figure 1. Structure of model.

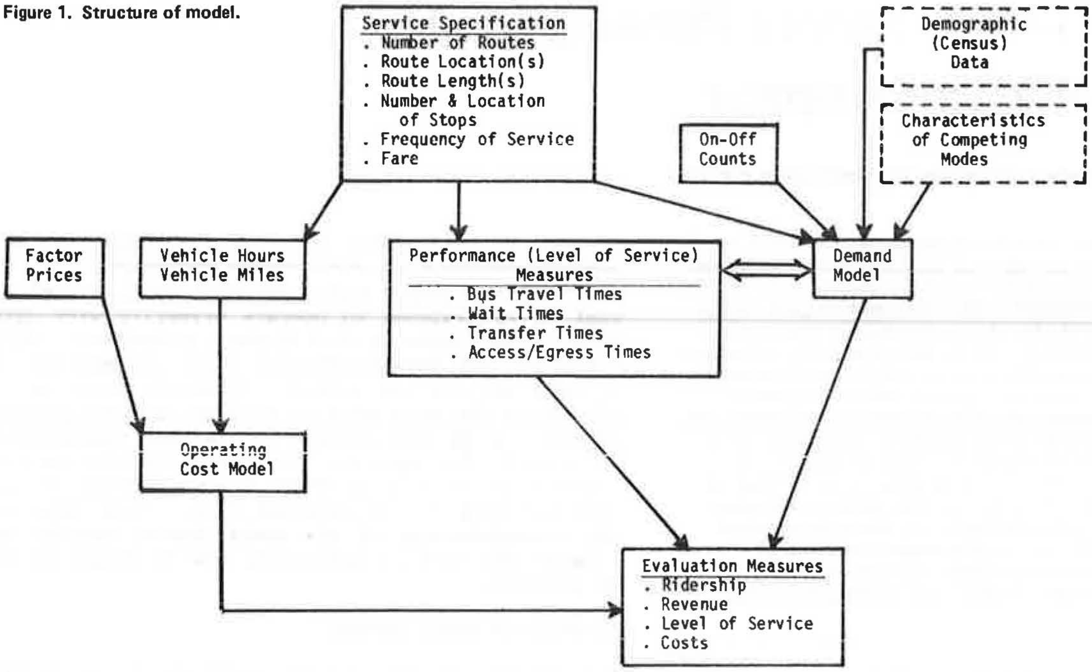
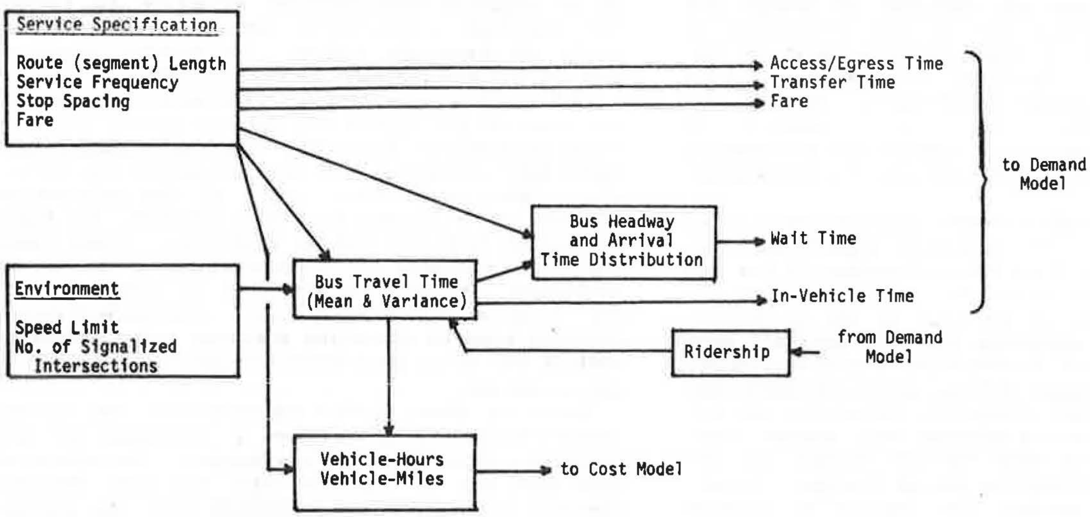


Figure 2. Overall structure of supply model.



Predictions of access or egress time depend primarily on stop spacing and the assumed maximum access distance. For most services, the access or egress mode will be walk. However, for some express services the predominant access or egress mode may be automobile (park-and-ride or kiss-and-ride). In this case the access or egress time may be substantially different.

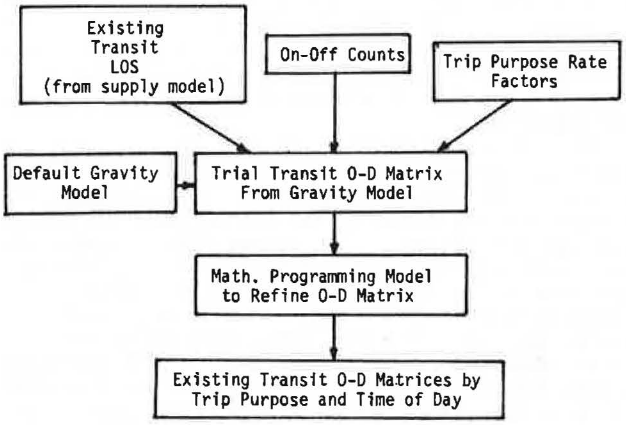
Maximum walking distance will typically be about 0.25 mile (400 m). [As an example, see the analysis done by Bakker (5).] This value was used as the maximum walking distance in our analysis. Together with an assumed average walking speed of 3 mph (4.8 km/h) and the stop spacing of the transit routes, this determines average access or egress time as an element of LOS. If desired, the maximum walking distance can be changed quite readily.

Prediction of mean bus travel times along route segments is important for average predictions of in-vehicle time. Also, prediction of the variability of bus travel times is necessary for use in the wait-time model. Our approach to travel-time prediction is based on the previous work of Turnquist and Bowman (6) and Jordan and Turnquist (7), although there are some minor modifications.

The mean travel time on a route segment is estimated as a function of segment length, speed limit, number of signalized intersections, average total boardings and alightings per bus, and average number of stops made to serve passengers. This functional specification is the result of analyses that use data from Cincinnati, Ohio. Note that the effect of ridership on LOS is clearly evident here, as mean time is affected by the number of passengers served and the number of stops made.

Once the mean travel time is estimated, the standard deviation is estimated simply by assuming that the distribution of travel times has a constant coefficient of variation. The standard deviation of

Figure 3. Model for estimating existing transit ridership.



travel time is an important input to the waiting-time model.

The model used to predict wait time is based on the model described by Bowman and Turnquist (8). This model predicts an arrival pattern of passengers at a stop by using information on expected headways between buses and the variability of arrival times (with respect to schedule) of buses at the stop. Thus, it includes the effects of both mean headway and service reliability on passenger wait time. It can be used over a wide range of headways; for very short headways it produces essentially the same results as simpler random-arrival models of wait time but matches observed waiting times much better than the random-arrival models for less-frequent services.

Finally, an expression for the expected transfer time when passengers board a first-leg vehicle without regard for the schedule of services on the second leg has been derived by Sen and Morlok (9). They term this the non-selective-arrivals case, and it is the most appropriate case for use in transit applications.

The total LOS vector, which includes access and egress time, wait time, transfer time, in-vehicle time, and fare, is then available for input to the demand models. Access and egress time, wait time, and transfer time can also be aggregated into a single variable (out-of-vehicle time) if desired.

Estimation of Operating Costs

The basic method for cost estimation in the model system relies on unit costs for vehicle hours and vehicle miles. The system-performance models produce estimates of vehicle miles and vehicle hours that result from the service change being tested. Vehicle ownership, maintenance, and fuel expenses are based on vehicle miles by using information on both physical relations (e.g., fuel consumption of buses) and current prices (fuel price, interest rate, maintenance labor wage rate, etc.). Vehicle hours are used to estimate driver and superintendence labor costs. The unit cost reflects wage rates and labor productivity factors, which may vary from peak to off-peak periods.

Total costs are computed as the sum of labor, vehicle ownership and maintenance, and fuel costs. Operating costs are given by total costs less the vehicle ownership (capital) cost. This procedure is intended to estimate the short-run incremental costs of service changes and thus does not include overhead costs that reflect general administration, insurance, etc., which would not be expected to change.

A second option on cost estimation is to base the analysis on more detailed timetable information rather than simply on a rough approximation of total vehicle hours and vehicle miles. If a complete timetable of services is provided for all routes under analysis, the number of vehicles required can be computed by using the concurrent scheduler described by Bodin and Dial (10). This algorithm also produces an accurate estimate of vehicle miles, including deadheading. A better estimate of labor costs can also be developed by using another method described by Bodin and Dial (10). This method is based on the out-of-kilter flow algorithm (11) and gives an accurate estimate of the number of drivers required to provide a given service.

The concurrent scheduler produces estimates of the number of vehicles required and the vehicle miles operated. This gives an accurate basis for estimating vehicle ownership, maintenance, and fuel costs. The out-of-kilter algorithm estimates the number of drivers, which is the basis for labor-cost estimation. This cost-estimation model is more complicated than the basic method and requires more data, but it gives more reliable estimates. This option is currently being implemented in the model.

Demand Model

The demand-model components are used in two ways. First, a procedure is provided to estimate base-case ridership by origin-destination (O-D) pair and trip purpose for the existing service. Second, an incremental analysis method is used to predict changes from that base-case ridership that results from changes in the service provided.

The establishment of existing ridership patterns entails derivation of transit O-D matrices by time of day and trip purpose. If the transit operator does not have O-D data available already and does not wish to collect such data through on-board surveys, the basic approach is to use transit on-off counts to obtain the required O-D matrices. As indicated in Figure 3, this involves calculation of a trial O-D matrix by using a gravity model; this matrix is then refined by a mathematical optimization model to yield a matrix that replicates the observed transit link loadings during the time period of interest.

Such on-off counts also provide actual values for two important independent variables in the bus travel-time prediction function that were mentioned earlier in the discussion of the supply model. These variables are the average number of total boardings and alightings per bus on each segment and the average number of stops made to serve passengers along each segment.

If desired by the user of the model system, the construction of the trial O-D matrix can be done by using multiple trip purposes. The total productions and attractions at each zone are split by trip purpose by using the percentages given by Sosslau and others (12), and the gravity model uses impedance coefficients that are trip-purpose specific. The resulting trial O-D matrices are then combined to form a total trip matrix before being input to the second-stage optimization model.

The basic approach to predicting ridership response to changes in LOS involves application of incremental demand techniques. These techniques pivot on the existing ridership levels and LOS to derive new ridership estimates based on the new LOS. The final ridership estimates and LOS are the result of equilibration between transit supply and demand.

Two incremental demand-modeling methods are employed. They implicitly assume that base ridership for existing transit service is accurately predicted and emphasize the use of relatively simple analytical techniques. The methods differ only in terms of the sophistication and underlying rationale of the incremental models used to predict the impact of service changes. The first method employs travel-demand elasticities, and the second method uses both full and incremental forms of the multinomial logit (MNL) model.

Elasticity analysis is the simpler of the two methods to apply. It avoids calculation of total corridor travel volumes and market shares and focuses only on the existing transit trip interchanges and existing and proposed LOS. Explicit treatment of competing modes can therefore be ignored under the assumption that transit service changes have no effect on the LOS of other modes.

The extreme simplicity of the elasticity method is both an advantage and a limitation. Note that not only are there various definitions of elasticities that affect their value, but elasticities are dependent on both the position and slope of the demand curve and are strictly appropriate to one point on the curve. Thus, the method should only be applied for relatively small changes in LOS variables. Also, it might be argued that elasticities are unlikely to be transferable over time and across locations and socioeconomic groups. Nevertheless, some consistency has emerged in empirically estimated elasticity values, and elasticity methods continue to be useful tools of analysis.

The second incremental demand method employs both full and incremental forms of the MNL model. This method therefore requires explicit treatment of modes that compete with transit and calculation of their market shares, but it is theoretically more satisfying than the elasticity method. Changes in the impedances of competing modes also may be incorporated with the logit analysis, if desired.

The MNL model used as a default model in the analysis system was developed for the Twin Cities area of Minneapolis and St. Paul (13). It is a three-mode model (transit, automobile drive alone, and automobile group ride). Three trip purposes are considered (home-based work, home-based nonwork, and nonhome based) and separate equations are used for each. If the user desires, an alternate model can be substituted.

The calibration results for the Twin Cities indicate that this model incorporates LOS and socioeconomic variables relevant for transit route-demand analysis. The data for these variables are also accessible to the operator. The estimated parameters are consistent with other comparable MNL model calibrations, which is encouraging for transferability of the models. In addition, the transit disutility equation is sensitive to automobile access to the transit system, which is a useful feature if park-and-ride lots are to be analyzed. The home-based-work model also distinguishes between transit wait times for the first vehicle and time spent transferring to subsequent vehicles.

Evaluation Measures

The key issue in the selection of a set of measures by which a transit design alternative may be evaluated is to choose the smallest set that still includes all the desired information. It is important to keep the set as small as possible so that the analyst can understand and retain the important information about each alternative. On the other hand, it is vital that the set of evaluation measures be rich enough to accommodate evaluation from several perspectives. The previous work of Fielding and others (14) on transit service quality and performance measures is of particular value in this regard, since it has highlighted the importance of including both measures of efficiency (i.e., doing things right), which are of primary interest to the operator, and measures of effectiveness (i.e., doing the right things), which are of primary interest to the community.

After computation of a new solution, the user of the model system is offered the output options shown in Figure 4. Each of the four summaries provides values for the existing service as well as values for the new design. This allows direct comparison for each measure. The ridership summary includes information on total trips, passenger miles, and passengers per vehicle mile. The LOS summary includes average in-vehicle time, wait time, transfer time, total passenger hours, average O-D passenger speed, and average passengers per seat as a measure of crowding. The operating-statistics summary includes vehicle hours, vehicle miles, seat miles, average vehicle speed, and average load factor. The financial summary includes revenue and cost information. Figure 5 shows an example of the financial summary to illustrate the information provided and the general format of all the summary outputs.

For a more detailed examination of route performance, options are provided for a route-load profile and detailed output of O-D ridership. Figure 6 shows an example of a route-load profile as it appears on the monitor screen. This type of graphical output conveys a great deal of information very quickly and can be very useful for consideration of detailed schedule changes on a route.

It should be emphasized that the exact form of the output reports and the measures reported can be modified easily to meet the specific needs of a particular operator. Finally, note that there is a certain level of flexibility inherent in most of the evaluation measures proposed here. For example, the time reference frame can be chosen by the evaluator from among peak period, nonpeak period, hour, day, week, etc.

DATA REQUIREMENTS FOR USE OF MODEL

The basic philosophy of the model system is not only to allow meaningful analyses to be carried out with a minimum of data but also to allow more detailed and precise information to be used if it is available. This is accomplished by having many default parameters in the model. These default values are realistic numbers based on a variety of studies but should be overridden whenever possible by values based on detailed local information.

The minimum data requirements for analysis of a route (or routes) are as follows:

1. On-off counts by stop,
2. Fare,
3. Length of each route segment (in kilometers),
4. Number of stops (by segment),
5. Number of signalized intersections (by segment),
6. Speed limit (by segment),
7. Capital cost per vehicle kilometer,
8. Operating cost per vehicle kilometer, and
9. Operating cost per vehicle hour.

On-off counts are the basis for construction of the existing ridership by origin and destination. The counts themselves do not provide the information to connect origins and destinations for individual riders, but the procedure that described the demand model solves this problem. This method produces an O-D trip table that is consistent with the observed on-off counts and passenger volumes on vehicles. By

Figure 4. Menu of output options.

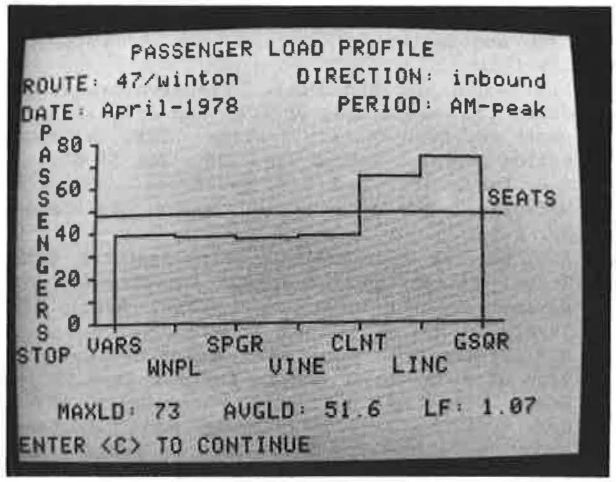
Figure 5. Example of financial summary output.

incorporating this method in the model, the transit operator is relieved of the need to supply a complete O-D table. This procedure is normally performed just once to establish existing (base-case) ridership patterns as a basis for predicting changes by using the incremental demand models as discussed earlier.

The route-segment information is used in the estimation of vehicle running times (mean and variance). These estimates, in turn, are used in computation of in-vehicle travel times, wait times, and operating costs.

Finally, unit cost data are the minimum information required for estimating changes in capital and operating costs that might result from various service changes. If the incremental logit model is used to predict ridership changes, additional information on automobile LOS and income data for the population must be provided. These data are not necessary if the simple elasticity model is used for predicting ridership changes.

Figure 6. Example of route-load profile.



CONCLUSIONS

This paper has described a simple and usable analytic model structure designed to provide the transit operator with a capability to search for and evaluate operating strategies that meet local transit service objectives. It has been shown that an effective supply-and-demand equilibration structure can be developed that is based on very limited and readily available data. Further, this model has been implemented on a relatively low-cost microcomputer.

The user can explore readily a number of changes in route-level operating policies. The cost model and evaluation measures allow the operator to assess the consequences of such operating policies. Thus, the model system represents an important new addition to transit operations-planning capability. Ongoing extension and development efforts will further enhance the attractiveness of the model system as a useful tool for transit operators.

Preparations are being made currently for field-testing of the model in two cities. These tests should begin in the summer of 1982, and results should be available by mid-1983.

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State of the Art of Current Bus Transfer Practices

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The use and consequences of alternative bus transfer policies are examined. A bus transfer policy consists of a set of operator actions that involves vehicle routing and scheduling, transfer charges, information for passengers, and terminal facilities that affects the movement of passengers between buses as part of a continuing trip. In this paper, the bus transfer policies currently in use on U.S. transit properties are described and summarized. Reasons why properties use or do not use particular transfer policies are identified, and the specific consequences of alternative transfer policies in different settings on cost, ridership, revenue, and user satisfaction are assessed. Situations or settings in which particular transfer policies can be applied beneficially are then identified and analyzed.

Abstract goes here

Under ideal circumstances, transit would carry all users directly from their orgins to their destinations without requiring a change of vehicles. However, given the geographic and temporal distribution of trips, such direct service is of course uneconomical for transit to provide. Therefore, operators must undertake some set of actions that involves such factors as vehicle routing, scheduling, transfer charges, and/or information for passengers (a transfer policy) to accommodate transferring riders.

This paper examines the use and impacts of the following 11 bus transfer-policy components, which are listed under four main components:

1. Routing components--distance between routes at transfer points and through-routing;
2. Scheduling components--schedule coordination, dynamic control of departure times at transfer points, timed transfers, schedule adherence on connecting routes, and service frequency on connecting routes;
3. Pricing components--transfer charge and use of transfer slips; and
4. Information components--provision of schedule information and marketing initiatives.

Note that the 11 transfer-policy components examined here do not exhaust the list of possible operator actions that affect transfers. However, most of the remaining ones (such as transit shelters, terminal facilities, and temporal or directional restrictions) are reviewed at least briefly in conjunction with one or more of the above components.

The material presented in this paper is drawn from the results of a recently completed study conducted under the Service and Methods Demonstration program of the Urban Mass Transportation Administration (UMTA) for the Transportation Systems Center (1,2). Data for that study were drawn primarily from a series of telephone and on-site discussions with experienced transit professionals on 39 different properties.

On any particular transit property, the demand for transferring clearly influences the type of transfer policy adopted. Relevant transfer demand characteristics include the following:

1. The percentage of riders who transfer (i.e., transfer rate),
2. Their socioeconomic and trip purpose characteristics,
3. Transfer-point locations, and
4. Directional and temporal characteristics.

The transfer rate is the percentage of transit person trips that involve transfers between transit vehicles. Often, the transfer rate cannot be calculated directly from available data but rather must be estimated from transfer slip data, passenger counts, or special surveys. Data problems include transit pass users who do not use transfer slips or riders who transfer more than once in the course of a trip. In general, however, it is possible to obtain reasonable estimates of transfer rates on most properties.

For bus-to-bus transfers, the average transfer rate on the properties examined is approximately 21 percent. However, several bus properties have a transfer rate on the order of 5 percent, while transfer rates as high as 50 percent have been ob-