Improved Service Strategies for Small-City Transit

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ABSTRACT

At a time when transit operating subsidies are threatened with drastic reductions, finding the most efficient way to provide adequate service has become extremely important. Models that have recently been developed to optimize or rationalize transit operations do not appear well suited to those small transit properties that form the majority of transit systems and are the most vulnerable to reduced subsidies. The Multiple-Route Transit Optimization Method (MRTOM) model introduced in this paper finds a set of solutions to minimize deficits in small-city transit systems. In the model, the transit system is considered a coordinated set of routes, not a series of individual routes that must be optimized separately. Solutions are presented as a list of the 20 best alternatives to consider, not a single, "optimal" solution that must be accepted or rejected. Each solution in the list includes integer-valued management variables (the number of routes and vehicles in each route) where appropriate, not continuous variables that must be rounded off at the user's risk. As with other models that have comparable objectives, several simplifying assumptions have been made. Tests conducted to date indicate that MRTOM provides useful answers that expand the perspective of the transit manager and the flexibility of the decision-making process.

The job of managing a public transit authority has never been easy. Public transit operations typically arose from the ashes of debt-ridden private transit firms whose rolling stocks and physical plants reflected the ravages of deferred maintenance and inadequate cash flow. In the days of public takeovers, public sentiment and public funding supported the newly established transit operations, but expectations were greater than the resources that were provided. A service region large enough to satisfy the public and its representatives was usually not conducive to economically viable transit operations. Operating costs, especially fuel and labor, rose to threaten transit's self-appointed role as a public utility. Instead of managing a firm, the transit manager was forced to concentrate on developing grantsmanship skills to accumulate every available federal subsidy dollar of the $31.5 billion that UMTA has distributed since FY 1965 (1). Since 1981, the UMTA operating assistance program has been threatened with being phased out by the Reagan Administration. Although Congress has resisted this proposal, the mounting federal deficit and a growing constituency calling for user fees and local responsibility make this threat ominous for transit properties.

In any case, the transit manager would be wise to seek ways to reduce operating deficits. Ideally, this should be done with minimal disruption to the existing system and the region served. Any proposed changes must be well supported by easily understood analyses that offer flexibility to all the actors in the decision-making process. A method is introduced and demonstrated in this paper that allows a transit manager to regain the ability to explore a range of options that preserve a desired level of service while enhancing the financial condition of the operation. The method had its origins in a transit performance evaluation model that has been accepted in the field and that has modest data requirements. Some of the model's distinguishing characteristics are presented in this paper, including an application to a representative small-city transit system.

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OPTIMIZATION OF TRANSIT SERVICE

There is a growing body of literature devoted to finding the best way to provide transit service. The objective is normally to reduce operating costs and deficits. The constraints are minimum levels of service (defined in such terms as headway, walking distances, and population served) and upper limits on fares and expenditures. The management choices available to the operator include the number of routes, route lengths, vehicles per route, service frequency, and fare.

The first efforts made toward optimizing transit service probably involved performance evaluation models that provided a computerized means of predicting and evaluating the outcome of proposed transit service changes. Single-route and transit corridor level demand forecasting and optimization models followed (2-9). More recently, systemwide optimization procedures have been attempted (10, Ch.1). The problem is complex and each approach to a solution to date has been based on certain simplifying assumptions. A typical simplification is that all routes will exhibit the same demand characteristics (11,12). In fact, the solution may specify a certain number of identical routes. Another practice that is becoming common is to solve the mathematical programming formulation as a linear program, which assumes that decision variables may take on noninteger variables (10,13). This assumption becomes risky in a problem in which the key variables (number of routes and number of vehicles per route) must be integer-valued; the smaller the transit system examined, the riskier this assumption becomes. A solution that specifies, for instance, 8.60 identical routes with 2.35 vehicles per route is not likely to be well received by the operator of a small transit system. A noninteger service frequency (buses per hour) is possible, but it complicates the provision of consistent schedules or timed transfers, especially in smaller cities.

The method described in this paper also makes certain simplifying assumptions, but they are quite distinct from those just mentioned. Because 25 of Indiana's 30 publicly supported transit properties have peak-hour fleets of 26 vehicles or less (14), a special interest is taken in small transit systems, which are the systems that will be most severely threatened by reductions in operating subsidies. The assumptions in this paper were made with respect to the integer nature of the small transit operator's decision variables and to the preservation of the distinction nature of each existing route. The dominant form of transit service in small systems--the pulse system--is also exploited in order to define a reduced set of options to consider in the model. This model was not designed for large systems, but it is a more appropriate tool for managers of small transit systems to use than the continuous models that appear in the literature.

PROVIDING MORE EFFICIENT SERVICE

For a number of reasons, transit system managers are interested in determining what the most efficient route configurations would be if they were free of the fare, route length, and service area requirements or incentives imposed by various levels of government. The findings might inform the manager of

- Clues to revising the system to better operate within the current environment of regulation and subsidies,
- Which subsidy allocation schemes to support and oppose as they are reviewed at the state level, and
- What form service might have to take if current subsidy levels are drastically reduced.

A logical problem formulation might proceed as follows:

1. Objective: minimize system operating deficit;
2. Requirement: carry at least as many riders as are currently carried;
3. Operational variables: fare, route length, and frequency of service; and
4. Data: current values and historical records.

The general manager might first choose to examine individual route corridors to determine the effects of service changes. In each corridor, the intent would be to find which combination of fare, route length, and service frequency would both minimize the operating deficit and maintain current corridor ridership levels. Initially, there would appear to be a large number of combinations to try, but the manager would be wise to first consider those service frequencies that most easily fit within the pulse system concept: one, two, or four buses per hour. The corresponding route lengths can be approximated for each frequency given the average operating speed, the number of vehicles per route, the maximum round-trip time, and a specified layover time (see Table 1). Of course, other options are possible (including noninteger frequencies), but even the pulse system concept can lead to a large number of combinations.

Three ways of providing a service frequency of four buses per hour (i.e., with one, two, or four buses) are shown in Table 1. Longer routes are possible with more buses, but operating costs will also increase. Will the greater ridership levels of the longer routes offset the additional expense? A reliable forecast of ridership is needed to answer that question. Once the number of buses on a route is determined, it must be decided whether longer routes or greater service frequency is desired. A demand forecasting technique is again needed to compare response to different service configurations. The manager knows what each corridor's current operating values are (fare, route length, and service frequency), and what the current ridership level is. The manager will also typically have a good idea of which demand elasticities will be useful in a demand forecasting technique.

TABLE 1 Definitions of Standard Route Options (BxFy)

Option	No. of Buses	Frequency	Route Length (mi)	Round-Trip Time (min)
B1F4	1	4	2	10
B1F2	1	2	5	25
B2F4	2	4	5	25
B1F1	1	1	11	55
B2F2	2	2	11	55
B4F4	4	4	11	55

Note: Route length and round-trip time values are approximations based on an average operating speed of 12 mph, a CBD layover duration of 5 min, and a maximum round-trip time of 55 min.

DEVELOPING A DEMAND FUNCTION

The responsiveness of ridership levels to changes in fare, in-vehicle travel time (IVTT), out-of-vehicle travel time (OVTT), or other variables is usually described in terms of elasticity. Because the method by which elasticity is incorporated into a demand model can have a significant impact on the model's behavior, various methods of measuring demand response to changes in service variables were examined (15) and the following demand function was adopted:

$$Q = K\ (IVTT)^{\alpha}\ (OVTT)^{\beta}\ (FARE)^{\gamma} \tag{1}$$

This equation is a product form of the demand function. Because the usual objective is to predict the level of ridership (Q) that will result from new values of FARE, IVTT, and OVTT, based on existing values Q_O, $FARE_O$, $IVTT_O$, $OVTT_O$, and calculated or assumed elasticity values, Equation 1 is more useful when expressed as the following:

$$Q = Q_O\ (IVTT/IVTT_O)^{\alpha}\ (OVTT/OVTT_O)^{\beta} \times (FARE/FARE_O)^{\gamma} \tag{2}$$

Equations 1 and 2 make use of point elasticities, which are different from the shrinkage ratio, arc elasticity, and pivot point methods of quantifying ridership changes in response to changes in service variable values. Point elasticities possess the mathematical consistency, convenience, and precision required in the iterative equilibrium-seeking components of the model (15,16).

THE MANUAL ANALYSIS CONTINUED

Even with such a mathematically convenient and consistent demand model, the manager would still have much work to do to implement a manual corridor analysis. For each service combination in Table 1, the manager must seek a fare that generates enough revenue to minimize the operating deficit and still meet a prescribed ridership target, for example, the status quo. The service combination that leads to the lowest deficit solution is the preferred strategy in the corridor under study.

If this manual method appears tedious, it is only part of the story. Another dimension must be added to these calculations. If patronage levels increase, so will the time to board and discharge passengers, which would result in a reduction of the overall operating speed and the route length possible to cover during a specified round-trip time. As the length of the route is reduced, so is the ridership level, until a route length equilibrium is reached for a given combination of Q_O and FARE. Of course, each time FARE is changed in a search for a minimum-deficit condition, the equilibrium is disturbed and must be reestablished.

Models are available on which to base this process of searching for an equilibrium. One of these models is the Transit Performance Evaluation Model (TPEM), which can be modified to take inputs of the sort involved in the manual analysis and convert them to ridership and deficit values (17). Although TPEM can ease the computational burden associated with a corridor analysis, the user must still provide one set of input values after another in a trial-and-error search for a minimum-deficit solution that maintains existing ridership levels. TPEM was the stepping-stone to the method introduced in the following section.

AN AUTOMATED METHOD

The type of corridor analysis described earlier is clearly awkward and tedious. Furthermore, the results of an analysis of a single corridor would be of limited practical value in an analysis of the com- plete transit system. It is quite likely that each corridor's separate equilibrium solution would lead to a different FARE value, but route-specific fare structures are inequitable and unacceptable. A proper systemwide solution with a common fare structure that maintains total system ridership and clearly specifies the best service configuration for each individual corridor is certainly beyond the capability of any manual or intuitive procedure. A computerized Multiple-Route Transit Optimization Method (MRTOM) was developed to generate systemwide solutions for the transit manager to consider (16). The following list summarizes the major steps in MRTOM:

1. Read basic input for system and each route (see input list that follows this list);
2. Convert basic input into characteristics for each route that are suitable for processing by MRTOM;
3. For each option (BxFy, where B is bus, F is frequency, and x and y are their respective numbers) on each route find the route length and ridership level that correspond to the minimum deficit at the cur- rent average fare; these are known as the initial equilibrium solutions;
4. For each system service combination, adjust the system fare and each route's length to minimize the deficit and achieve the target ridership level; and
5. Output: rank system combinations with the lowest deficits; list the best 20. Rank system combinations that have the lowest deficits and fares within a prescribed range; list the best 10 (see the output list).

The basic inputs for MRTOM are as follows:

Required input:

- Operating cost per vehicle hour ($);
- Operating cost per vehicle mile ($);
- Average fare ($); and
- For each existing route: route identifier, round-trip length (mi), round-trip travel time (min), number of buses in service, frequency (buses/hr), stops per mile, ridership per hour, and service options to consider.

Optional (input defaults available):

- Average boarding or alighting time (sec/passenger);
- Stopping/starting delay (sec/stop);
- Minimum and maximum acceptable fares;
- Elasticities (FARE, IVTT, and OVTT);
- Assumption regarding relationship between ridership level and route length; and
- Definition of each route service option to consider: frequency (buses/hr), round-trip time (min), number of buses on route, and average out-of-vehicle travel time (min).

MRTOM provides the following output:

- Echo of input data;
- Route characteristics derived from input data: vehicle speed, average OVTT, boarding and alighting passengers per stop, and operating deficit;
- Preliminary equilibrium solution for each option selected on each route at current average fare;
- Twenty system combinations with the lowest operating deficits, consisting of a specified option (BxFy, route length) for each route; route-by-route estimates of ridership and speed, and system fare, ridership, and operating deficit; and
- The 10 lowest-deficit system combinations within the prescribed range of fares (with same details as top 20 combinations).

APPLICATION TO AN ACTUAL SYSTEM

With a peak-period fleet of 17 buses, the Greater Lafayette Public Transportation Corporation (GLPTC) is representative of most transit systems in Indiana and many small-city transit systems in the United States. GLPTC operates 13 routes on a timed transfer basis, with a transit center in downtown Lafayette. During the average peak hour, the ridership level is 248 and the operating deficit is about $285. The current peak service is summarized in the second column of Table 2. When selecting options for each route from among the seven options available, the following rules of thumb should be applied:

- If a route has a cost recovery ratio (reve-

TABLE 2 GLPTC Peak-Period Analysis

Route No.	Current Service Combination[a]	MRTOM Lowest Deficit Solution[b]
1	B1F2	B1F1
2	B1F2	B1F1
3	B1F2	B1F1
4	B4F4	B1F1
5	B1F2	B0F0
6	B1F2	B0F0
7	B1F2	B1F1
8	B1F2	B0F0
9	B2F4	B1F2
10	B1F1	B1F1
12	B1F2	B1F1
13	B1F2	B1F1
15	B1F2	B0F0

[a]Avg fare, $0.346; system deficit, $285/hr; peak fleet, 17 buses.
[b]Avg fare, $0.367; system deficit, $105.24/hr; peak fleet, 9 buses.

nues divided by operating cost) below the system average, include the B0F0 (discontinue route) option.

• Do not select options BxFy for which hourly $Q_o > y * V$ in peak periods or for which hourly $Q_o > y * 2V$ in the off-peak period, where y is frequency and V is the maximum acceptable number of passengers to be carried on a bus. This screens out most of the relatively infrequent capacity-violating cases before the solution process begins.

• Because option B1F2 is generally a weak option, try a longer route with the same (B2F2) or minimal (B1F1) service, if capacity constraints will allow it.

• To make up for ridership lost elsewhere, especially where the B0F0 option is used, try to increase service on routes with better-than-average values of ridership, cost recovery, and deficit per passenger.

The first test of MRTOM is its ability to reproduce existing conditions. Using cost data and an allocation formula provided by GLPTC, the average peak-hour deficit was estimated to be $285. MRTOM's route-by-route deficit calculations, which were derived from the input data, sum to a deficit of $286 per peak hour. Because both values are estimates, the almost exact match of the two cannot be taken too seriously, but at least MRTOM's solution process has a sound starting point.

MRTOM's lowest deficit solution is shown in the third column of Table 2. Besides reducing the peak-hour operating deficit by 63 percent, the solution requires only nine peak-hour buses. Thus, possible capital savings are also identified.

The full output displays the 20 distinct service combinations that have the lowest deficits, from $105.24 to $115.41 per peak hour. In each of these 20 best solutions, four or five of the six routes with the lowest current cost recovery values are abandoned. The ridership lost on these routes is recovered by making most surviving routes longer and, presumably, more circuitous. The conversion of the B1F2 option to the B1F1 option is a common example in Table 2 in which a 25-min route that is operated twice an hour is converted into a single 55-min round-trip. The 20 combinations provide the decision makers with a basis for comparison to evaluate which routes to abandon, and a financial analysis with which to balance political arguments. For example, Route 15 is always assigned the B0F0 option in the 20 best solutions, while Routes 5, 6, and 8 are slated for abandonment (or partial coverage by expanded adjacent routes) at least 17 times each. Routes 3 and 7 get the B0F0 option 4 and 10 times in the top 20 solutions, respectively, but never in the same solution. MRTOM's list of 20 solutions illustrates various trade-offs and informs the decision-making process; it does not attempt to replace that process.

The list of solutions can also indicate trends that call for more careful analysis. The conversion of many B1F2 routes to the B1F1 option is based largely on the presumption of relatively inelastic peak-hour demand with respect to IVTT ($\alpha = -0.35$) and OVTT ($\beta = -0.70$) (17). These elasticities are often based on outdated or borrowed data. A special survey or a single-route trial service change may be needed to update these values before systemwide service changes are inaugurated.

Sometimes none of the 20 best system combinations is totally acceptable to the decision makers. For example, a policy of one-hour headways and acceptance of route abandonment in more than one or two corridors may not be politically desirable. Running MRTOM again with a correspondingly revised set of route service options will produce a new list of 20 system solutions with deficits and service values that can be compared against the original, less politically constrained list. Both solution lists will be optimal within the constraints reflected in the route options selected. MRTOM allows a more explicit analysis of the cost (increased subsidy) of adding or retaining service above the basic level needed to meet a specified ridership.

TESTING MRTOM FOR FLEXIBILITY AND FEASIBILITY

Several sets of analyses were performed to test the model and learn more about the pattern of solutions it provided. Besides the deficit reductions possible in each case studied, several interesting, logical results can be observed. Some of the findings are listed as follows (16):

1. The B0F0 strategy (discontinue route) occurs more often for lower system Q_o's. This strategy may be politically infeasible, but the presence of alternative combinations without B0F0 strategies in the solutions list allows the cost of such political considerations to be assessed.
2. Discontinuing service on the least-patronized routes leads to lower fares on the remaining routes. It is more economical to attract more passengers on the remaining routes by lowering fares than to maintain service on routes with low ridership levels. Of course, these economic considerations may be overruled, but the list of solutions includes many alternatives that can be checked against other criteria.
3. The MRTOM solutions list repeatedly demonstrates the trade-off between better service and lower fares. A higher service frequency is compensated for in the MRTOM equilibration phase by a higher fare.
4. The flexibility in choosing among alternative service combinations is demonstrated by the fact that drastically different solutions can appear near each other in a list. In one list, the sixth best combination consisted of no service to Route 2 and low fares (15 cents) with minimal service (B1F1) on the remaining routes. The next best combination in the list offered a relatively high level of service (B4F4/B2F2/B1F1) with an average fare of $1.76. If neither a loss in service nor an increase in fares is acceptable, a compromise combination usually appears nearby in the list.
5. The B2F4 option seldom appears in any solutions list. If two buses are to be used on a route, the B2F2 option is a superior solution as long as serving a longer route attracts more new passengers than serving a shorter route twice as often. If a frequency of four buses per hour is desired, the B4F4 option likewise permits a longer route length than the B2F4 option and, in most of our examples, either a higher ridership level or a lower deficit for a given fare, or both. In the tests conducted, the B1F4 option was not competitive for a system with an average route ridership level greater than 25 per hour, but it consistently outperformed the B2F4 option until the high small-city ridership level of 100 per hour per route was reached.

The relative frequency of a combination's appearance in a solutions list largely depends on its elasticity values. If service elasticities (IVTT and OVTT) are more sensitive than fare elasticity, then MRTOM can be expected to favor combinations with higher service frequencies and some limitations on route length based on the number of buses in use. After this proposition is tested, long-route low-frequency combinations could be manually excluded from the input (i.e., not requested) to reduce computation time.

SUMMARY

Recent attempts at optimizing the operations of transit systems (10,11,16) reflect both the increasingly difficult financial environment of transit systems and the trend toward applying more sophisticated analytical tools to systemwide (rather than route-by-route) analysis. These tools will be more quickly accepted if they are not unrealistically "data-hungry" and if the results are truly useful. The objectives of the MRTOM model described in this paper are to (a) provide a decision aid to the small-city transit manager, (b) take a large step toward true optimization of transit systems, (c) make the best use of data currently collected, and (d) provide a variety of useful solutions to enlarge managers' decision-making perspective instead of confining them to a single, "optimal" solution. In order to accomplish those objectives, MRTOM is based on certain simplifying assumptions that differ from those in other models. The assumptions in MRTOM appear to be reasonable in the context of small-city operations, based on the quality of results of a variety of hypothetical cases and on tests run on actual transit systems.

ACKNOWLEDGMENT

James Poturalski and Jarkko Leinonen deserve considerable credit for their contributions to this research effort. The authors are also grateful to Fred Williams and Nat Jasper of UMTA for their assistance and patience during the conduct of this project.

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