

passengers would be required to travel during the peak than off-peak period to offset the peak period operating costs. For lines 262 and 602, respectively, approximately 39 and 13 percent more passengers would be required to travel in the peak than the off-peak periods.

Clearly, a cost centers modeling approach, based on an understanding of the variations between local and express services as well as peak and off-peak operator pay-hours, has increased SCRTD's capability to estimate marginal line-by-line operating costs. Operating costs associated with different times of day, different types of service, and different days of operation can be identified. Given that even greater variations in divisional expenses are known to exist, sensitivity analyses by type of expense account can also be performed. Cost-effectiveness sensitivity analyses by bus type, for example, can be developed if differences in fuel, tire, and other expenses can be quantified. Although the development of six distinct models has increased the difficulty

of the cost estimation process, the increases in accuracy appear to justify the disaggregate modeling design. Although significant modifications of SCRTD's labor agreements or service types, or both will influence the degree of accuracy of the peak and off-peak models, minor modifications can be absorbed in periodic calibrations of each model to the SCRTD operating budget.

REFERENCE

1. W. Cherwony and S. Mundle. Peak-Base Cost Allocation Models. In *Transportation Research Record* 663, TRB, National Research Council, Washington, D.C., 1978, pp. 52-56.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Abridgment

Transit Routing and Scheduling Strategies for Heavy Demand Corridors

PETER G. FURTH and F. BRIAN DAY

ABSTRACT

Efficient routing and scheduling strategies for heavy-demand corridors are described. Examples are given. Four strategies pertain to local service: short-turning, restricted zonal service, semirestricted zonal service, and limited-stop zonal service. Zoning of express services and deadheading of both local and express service are also discussed. Advantages and disadvantages of the strategies, and conditions favoring their adoption, are discussed.

Transit service in radial corridors can often take advantage of a high level and concentration of demand by employing routing and scheduling strategies that are more efficient than the conventional local route. For the purposes of this paper, a corridor is the narrow area served by a single local route or by a set of routes operating on the same street, and a "heavy-demand corridor" is one in which peak passenger volume is roughly eight or more busloads per hour. Although service in such corridors will rarely be identified through service standards as substandard, it is nevertheless often possible to increase its productivity significantly through the use of routing and scheduling strategies tailored to the markets. Because of the large amount of service offered in these corridors, improved productivity here can lead to substantial operating cost reductions. Several of these strategies are described and their advantages and disadvantages are discussed. Proposed and actual examples of their applications are presented. A fuller description of these strategies is

found in Furth et al. (1). Procedures for analysis and design are documented elsewhere (2-6).

ZONAL EXPRESS SERVICE

By separating the long-distance, central business district (CBD)-oriented market from the remainder of the transit market, the former can be more efficiently served with express service. Express routes are faster because they make fewer stops and can use high-speed roads for the express portion. If they can charge higher fares, they are all the more cost-effective. However, lower design load factors required on some express routes can lower their productivity.

If the demand for express service is at least six or eight busloads per hour (i.e., large enough to support at least two routes), express service can often be made more efficient by splitting the express service area into zones and serving each zone

with its own express route. There are three advantages to zoning: (a) the routes serving the inner zones do not travel the full length of the corridor, (b) each route's service area is more concentrated so that each trip requires fewer stops to fill a bus, and (c) the outer zone routes can sometimes use high-speed roads or take advantage of signal progression as they travel express over the inner zones. The disadvantage of this strategy is that wait times will increase because the demand, and hence frequency of service, will be only a fraction of that of an unzoned express route serving the same market.

SHORT-TURNING

The short-turn strategy consists of a system of two (or more) service patterns along the same street in which the shorter pattern is entirely overlapped by the longer. The shorter pattern is commonly referred to as a "short-turn" or "turn-back" variation of the full-length pattern. No boarding or alighting restrictions are imposed on any sections of the routes. This strategy is suitable for corridors in which demand tapers off in the outer segments. Operating cost is reduced because short-turn trips are substituted for full-length trips. Because of the lowered frequency of full-length trips, wait time increases for passengers whose trips are not served by the short-turn pattern. Service level does not change appreciably for those whose trips are served by the short-turn pattern. This latter group is called the "choice market" because they can use either the short-turn or the full-length pattern depending on which bus comes first.

The existence of a large choice market necessitates schedule coordination between the service patterns to ensure that each trip of a given pattern has a (more or less) constant number of choice passengers waiting for it, or loads will be unbalanced. Efficient schedule coordination is most easily attained if each pattern has the same service frequency so that they alternate within the overlapped segment of the corridor (the portion served by both patterns). The offset between the patterns determines how large a share of the choice market each pattern gets. Because the full-length pattern has a captive market of its own and uses larger vehicles, short-turn trips should lead the full-length trips by a small interval so that most of the choice market uses the short-turn pattern. For example, full-length trips might pass a checkpoint in the overlapped segment at 10, 20, 30 min after the hour and so forth, and short-turn trips might pass that point at 8, 18, 28 min after the hour and so forth.

RESTRICTED ZONAL SERVICE

A major determinant of which strategy will be most efficient for local service is the degree of downtown orientation in the local transit market, measured by the ratio of the corridor's peak volume to its uptown boardings (uptown alightings for the outbound direction in the p.m. peak), called the PV/UB (PV/UA) ratio. Uptown boarding (alighting) is defined as the volume of passengers boarding before (alighting after) the peak volume point. A small PV/UB ratio implies a lot of passenger turnover before the peak volume point and thus favors a strategy such as short-turning that freely allows for passenger replacement. However, when the PV/UB ratio is near 1, few passengers alight before the peak volume point, so allowance for turnover is not as important.

For restricted zonal service, as for the zonal express strategy, the corridor is divided into two or more zones with a particular route designed to serve each zone. Inbound buses on a restricted zonal route begin at the outer boundary (farthest outlying stop) of their service zone, operate locally within the zone, and then remain on the local street as they continue toward downtown. Unlike zonal express service, the buses may stop at any stop on the trip inbound to allow passengers to alight. Similarly, outbound buses will stop at any stop to allow boarding only (no alighting) between the downtown and their service zone; they then operate locally within their service zone. This arrangement is called a local service strategy because it still makes it possible to travel directly between any pair of bus stops in the corridor.

Restricted zonal service, like zonal express service, lengthens wait times throughout the corridor because all passengers must wait for the one route that serves their origin-destination pair. However, speeds increase for outer segment travelers because their buses are able to skip many inner-segment stops. In long, high-demand corridors, the reduction in travel time can sometimes offset the longer wait times for outer-segment travelers.

Like the short-turn strategy, the restricted zonal strategy reduces the number of trips operating in the outer segments of the corridor, thus reducing vehicle requirements. Higher speeds on the longer routes can further reduce vehicle-hours needed. However, some of these advantages are offset by the effect this strategy has on the turnover of seats. For example, once an inbound bus leaves its service zone, no one may board to replace alighting passengers. (The mirror-image behavior occurs on outbound buses.) The peak load of a restricted zonal route will therefore occur at or before the inner boundary of its service zone. Thus, the load on the bus as it enters the downtown will be less than the load it carried leaving its service zone because of the alighting that occurs as the bus operates in the restricted mode. Therefore this strategy is best suited to corridors with a high PV/UB ratio.

Restricted zonal service is used by the Massachusetts Bay Transit Authority (MBTA) along Massachusetts Avenue between Arlington Heights and Harvard Square in suburban Boston. The shorter route, Route 77A, operates locally between the North Cambridge terminal and Harvard Square. The longer route, Route 77.4, acts as a local route between Arlington Heights and North Cambridge and then goes into restricted operation between the North Cambridge terminal and Harvard Square. During the morning peak, Route 77A, which uses trolleybuses, makes 12 trips per hour with a cycle time of 40 min, requiring eight trolleybuses. Route 77.4, using diesel buses, makes 20 trips per hour with a cycle time of 75 min, requiring 25 buses. In comparison, a full-length local route serving the entire corridor would have a cycle time of about 80 min and would have to make 30 trips per hour. (The frequency of this single route is slightly lower than the combined frequencies of Routes 77A and 77.4 because it would allow free turnover in the inner zone.) Thus, a single local route would require about 40 buses, 21 percent more vehicles than the restricted zonal system now in place. Passengers also benefit from the restricted zonal configuration. Average wait time in the corridor is only 1 min longer under the zonal service than it would be with conventional local service (2.2 min versus 1.2 min), and in-vehicle time is about 5 min less under the zonal service for passengers originating before the North Cambridge terminal and unchanged for those originating after North Cambridge.

SEMIRESTRICTED ZONAL SERVICE

Inbound, semirestricted zonal service operates in a zone configuration like restricted service but differs in that it permits vehicles, if they stop outside their service zone to let someone alight, to let waiting passengers board. Thus, this strategy overcomes the inefficiency of the restricted zonal strategy by allowing for alighting passengers to be replaced. However, unfortunately, the strategy will not work in the outbound direction. The mirror image of the inbound policy is that outbound, if a passenger destined for an inner zone stop boarded an outer zone bus, he would be allowed to alight at his stop only if the bus happens to stop there to pick up a passenger waiting to board. With this kind of uncertainty, nobody traveling within the inner zone could be expected to use an outer zone pattern.

The level of service impacts of this strategy are between those of the short-turn and the restricted zonal strategy. This strategy is particularly attractive in moderate length corridors with a PV/UB ratio between 0.75 and 0.95. However, transit systems that have applied this strategy report that passengers will often complain because a bus that stopped to pick them up yesterday passed them by today. Such pressure has, in some cases, led to the discontinuation of the strategy. Another difficulty is that in the outbound direction, a different strategy, such as short-turning or restricted zonal service, must be used. A strong public information effort may be required to make this strategy successful.

LIMITED-STOP ZONAL SERVICE

This strategy is well suited to long corridors and does not require a high PV/UB ratio. Like zonal routes in other strategies, a limited-stop pattern has a service zone in which passengers may freely board and alight at any stop. However, outside the service zone, buses stop only at designated stops generally spaced 0.50 to 1 mile apart (except in the CBD, where every stop is usually designated). At these stops, passengers may both board and alight. The innermost route or pattern in a limited-stop zonal configuration is simply a local pattern (i.e., it has no limited-stop segment). If there is a lot of local traffic in the corridor, it is possible to have a local route parallel the limited-stop route the entire length of the corridor.

Like the short-turn strategy, this strategy generates a choice market of passengers who can use

either the limited stop pattern or the local pattern, whichever comes first. Many of these passengers will walk greater distances to be able to use the limited-stop pattern. Efficient service design requires (inbound) that use of the limited-stop pattern by choice passengers from the inner segment be limited as closely as possible to just replacing alighting outer segment travelers (the mirror image applies outbound). To accomplish this objective, several measures can be taken. In the outbound direction, most of the boarding usually occurs in and near the CBD, where limited-stop and local patterns all travel at the same speed. Thus, schedules can be coordinated as in the short-turn pattern to optimally share the choice market. In the inbound direction, schedule coordination can affect the division of the choice market to some extent, but its effect is limited because the buses operating limited stop will overtake the local buses, so that a constant offset cannot be maintained. Another feasible, though undesirable, way to efficiently split the choice market in the inbound direction is to simply use crowding as a deterrent within the inner segment. Finally, charging a higher fare on the limited-stop pattern, increasing the spacing of designated stops, and making only some CBD stops designated stops are all measures that will decrease the limited-stop pattern's share of the choice market, if that is needed.

An application of the limited-stop strategy is found in the Wilshire Boulevard corridor of Los Angeles, where Southern California Rapid Transit District (SCRTD) Route 308 operates local from Santa Monica to Beverly Hills and limited stop from there to downtown Los Angeles. Between Beverly Hills and downtown, the corridor is served by several local routes in a quasi-short-turn system. Compared to a simple short-turn system for the entire corridor, the popular limited-stop configuration reduces one-way travel time from end to end by 12 min, benefiting both passenger and operator.

DEADHEADING

It is common practice for express routes to deadhead in the reverse direction of travel. It is also possible for a local route to deadhead all of its trips in the reverse direction, as long as reverse direction service can be provided by another route. For example, in a two-zone system, the inner zone route could deadhead all of its trips, leaving the full-length route to provide local reverse direction service (provided the reverse direction demand is low

TABLE 1 Advantages and Disadvantages of Local Service Operating Strategies

	Short-Turn	Restricted Zonal	Semirestricted Zonal	Limited-Stop Zonal
Need for schedule coordination and strict adherence	Vital	None	None	May be valuable in a.m.; valuable or vital in p.m.
Reliance on overtaking	None	Strong	Moderate	Strong
Wait time impact ^a	Up by 90% in outer segment, by 20% in inner segment	Up by 90% throughout	Up by 90% in outer segment, by 20% in inner segment	Up by 90% in outer segment, by 20% in inner segment
In-vehicle time reduction	None	Considerable	Moderate	Considerable
Walk-distance impact	None	None	None	Up by 0.2 mile for some outer segment passengers
Difficulty in public comprehension	Little	Moderate	Considerable	Moderate
Most favorable conditions for vehicle savings				
PV/UB ratio (%)	40-90	90-100	80-99	Any
Corridor length	Short	Long	Any	Long
Ambient speed on transit route	Slow	Fast	Fast	Fast

^a Average impact to peak direction travelers in typical application.

enough). To avoid angering waiting passengers, many systems make it a practice to deadhead vehicles on streets that have no bus service.

Another deadheading option is to have only a fraction of the runs on a route return in service while the remainder deadhead. This strategy, called "alternating deadheading," is studied in Furth (6). The simplest alternating deadheading schedule is to have every other bus deadhead. In an application on an available freeway, alternating deadheading saved 4 of 29 buses on a busy route.

COMPARISON OF LOCAL SERVICE STRATEGIES

Table 1 gives a summary of the four major strategies for local service. Included are operational and public information problems, level of service impacts, and the conditions that most favor efficient operation of each strategy.

ACKNOWLEDGMENTS

This research was supported by UMTA through contract DOT-TSC-1756 to Multisystems, Inc. The technical monitor was Brian McCollom. A panel of officials from nine U.S. transit systems also provided valuable input.

REFERENCES

1. P.G. Furth, F.B. Day, and J.P. Attanucci. Operating Strategies for Major Radial Bus Routes. UMTA Final Report DOT-I-84-27. Multisystems, Inc., Cambridge, Mass.; UMTA, U.S. Department of Transportation, 1984.
2. P.G. Furth, F.B. Day, and J.P. Attanucci. Bus Route and Service Design: Application of Methods and Procedures. Draft Report. Multisystems, Inc., Cambridge, Mass.; UMTA, U.S. Department of Transportation, 1984.
3. M.A. Turnquist. Zone Scheduling of Urban Bus Routes. Journal of the Transportation Engineering Division of ASCE, Vol. 105, No. TE1, 1979, pp. 1-12.
4. F.J. Salzbom. Timetables for a Suburban Rail Transit System. Transportation Science, Vol. 3, 1969, pp. 297-316.
5. P.G. Furth. Zonal Route Design for Transit Corridors. Transportation Science (forthcoming).
6. P.G. Furth. Alternating Deadheading in Bus Route Operations. Transportation Sciences, Vol. 19, 1985, pp. 13-28.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Maintenance and Operating Costs of Small Buses

P. R. NAYAK, A. B. BOGHANI, D. W. PALMER, and P. G. GOTT

ABSTRACT

Maintenance and operating cost data are provided for small buses. These data were obtained by analyzing the maintenance and fuel use records of 187 small buses from 16 transit properties located in different parts of the country. Specific cost data are provided for four types of small bus: vans and modified vans, body on van chassis, body on truck chassis, and purpose built. Both the labor hours and the materials cost are calculated on a per mile basis. The effects of climate and duty cycle on maintenance cost are evaluated. The procedure used in collecting the data and the characteristics of the data bases developed to store and analyze the data are described.

One of the important decisions facing small urban area and rural transit decision makers, who are interested in establishing new transit systems, is whether to invest scarce public funds in lower-capital-cost, more-efficient, less-durable transit vehicles or higher-capital-cost, less-energy-efficient, more-durable ones. Although previous research has provided reliable life-cycle cost and fuel use estimates for taxi vehicles and full-size standard transit vehicles, little information is available for vanpool vehicles, medium-size transit vehicles, or nonstandard, full-size transit vehicles (such as

body-on-chassis-type school buses converted for transit use). If vehicle purchase decisions are to be soundly based, life-cycle cost comparisons and energy use information for those types of vehicles are essential.

Toward this end Arthur D. Little, Inc., undertook a project entitled "Small Transit Buses: A Manual for Improved Purchasing, Use and Maintenance" under the sponsorship of UMTA. This project was conducted through the National Cooperative Transit Research and Development Program. The general objective of this research was to develop a workbook-style manual