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Contents

Foreword

Although federal expenditures for urban public transportation research have declined sharply in recent years, the topic still interests many investigators. Each of the 10 papers in this Record will help advance the understanding of the subjects addressed.

In the first paper, Chatterjee and Wegmann discuss the difficult problem of providing transit service in low demand periods, such as Sunday. Next, Ceder presents a set of procedures for improving and automating short-turn trip scheduling and uses a simple example to illustrate the procedures.

Some 20 percent of the buses entering New York City are unfranchised and hence not subject to the usual city controls on traffic, economic, and community impacts. Levinson et al. suggest both short- and long-term ways to ameliorate the situation. In many industrialized nations, multimodal terminals are increasing in number. Bell and Braaksma used responses to an open-ended questionnaire to determine factors that could form the basis for the development of a multimodal passenger terminal policy for Canada. In the next paper, Proussaloglou and Koppelman describe an analysis framework that uses attitudinal data to support service design decisions for a public transportation system. A sample application of the framework to Chicago's commuter rail service demonstrates the method's effectiveness.

Gary, in his paper on line-haul rapid transit, considers the controversial issue of level of system automation. He concludes that automated systems have significant advantages over attended transit systems. An issue that is equally debatable is the effect of transit mode on ridership. In his paper on the impact of transit service on patronage, Tennyson presents evidence that the mode of transit service can make a significant difference. Estimation of annual operations and maintenance costs is an important part of the analysis required for obtaining federal funds for major capital transit investments. Miller et al. determine the implications for O&M cost estimation of several key productivity relationships in light rail transit systems.

The last two papers, which examine the problem of spare parts in bus transit maintenance, are based on a simulation model that considers the proper choice of spare ratio. In the first paper, Iskander et al. describe the development and successful validation of the model, and in the second paper, Jaraiedi and Iskander consider the relationship between variations in spare ratio and characteristics of bus transit properties.

Private Sector Involvement in Sponsoring Sunday Bus Service

ARUN CHATTERJEE AND FREDERICK J. WEGMANN

An increasing amount of deficit and lack of public funds to make up a financial shortfall forced the Knoxville Transit Authority of Knoxville, Tennessee, to eliminate the Sunday bus service operated by K-TRANS. The rationale for the elimination was that the cost-effectiveness of K-TRANS service was lowest on Sundays, in comparison with any other day of the week. Before Sunday service was discontinued, K-TRANS was accommodating ~750 trips (boardings) on an average Sunday, whereas the number of trips on an average weekday was ~15,000. After the decision to discontinue Sunday bus service was made public, the management of two regional shopping centers contacted K-TRANS and expressed their interest in sponsoring Sunday bus service to each mall for 12 Sundays during and after the November-December holiday season. Both routes were designed as loops to serve several housing complexes for low-income families and the elderly and several student housing units, as well as the respective malls and downtown area. The two distinct issues addressed are the effectiveness of providing privately funded transit service targeted for a selected market in an environment where transit ridership generally has been low and the effectiveness of a targeted service focusing on a few major generators in replacing an existing transit service with areawide coverage. The latter issue is of particular interest to planners.

On October 23, 1986, an increasing amount of deficit and lack of public funds to make up a financial shortfall forced the Knoxville Transit Authority (KTA) of Knoxville, Tennessee, to eliminate the Sunday bus service operated by K-TRANS. The rationale behind the elimination of Sunday service was that the cost-effectiveness of K-TRANS service, which is reflected by such indicators as passengers carried for each dollar spent and passengers per vehicle-mile of service, was lowest on Sundays, in comparison with any other day of the week. Before the Sunday service was discontinued, K-TRANS accommodated ~750 trips (boardings) on an average Sunday. In contrast, the number of trips on an average weekday was ~15,000 and on an average Saturday, ~6,000. The last day of regular Sunday service financed by public funds was November 1, 1986.

The Sunday service was discontinued in spite of a highly charged emotional protest from a citizen's group that voiced concern about the mobility needs of riders who had come to rely on transit service on Sundays. After the public learned of the decision to discontinue Sunday bus service, the management of East Towne Mall shopping center contacted K-TRANS and expressed their interest in sponsoring Sunday bus service to the mall for 12 Sundays during and after the November-December holiday season, with the cost of the service paid by East Towne Mall. Soon after learning of the proposed Sunday bus service to East Towne Mall, the management of West Town Mall approached K-TRANS with a similar proposal for supporting a route on the west side of town. Both routes were designed as loops to serve several housing complexes for low-income families and the elderly and several student housing units, as well as the respective malls and the downtown area.

OBJECTIVE

One of the issues addressed by this case study is the effectiveness of providing privately funded transit service targeted for a selected market in an environment where transit ridership generally has been low. The other issue, which is of interest to planners, is the effectiveness of a targeted service focusing on a few major generators in replacing an existing transit service with areawide coverage.

SERVICE OPERATION AND ROUTES

The schedules and service operation patterns were identical on both routes. Two buses were assigned to each route of the Shopper's Express service so that a total of four buses operated in Sunday service. On each route, one bus left downtown at 11:00 a.m. while the other left the shopping center at the same time. These two buses operated in opposite directions on the loop-shaped route, one clockwise and the other counterclockwise. The travel time from one end of the route to the other (mall to downtown) was 30 minutes. Buses therefore left each terminal of a route every 30 minutes. The last bus left a shopping center at 5:00 p.m., and that bus went to the garage after arriving downtown at 5:30 p.m. Before the service discontinuation, K-TRANS operated 12 buses on hourly headways between 8:00 a.m. and 4:30 p.m. The new Shopper's Express service duplicated ~36 percent of the regular Sunday route service.

Service on both routes began November 9, 1986, and operated for 12 consecutive Sundays. The fare was $0.50 per ride for all passengers, and free transfer was permitted between the two routes. In comparison, the fares for regular Sunday service were $0.75 for adults, $0.35 for the elderly and handicapped, and $0.20 for transfers.

The routes were designed by the staff of K-TRANS in consultation with the sponsors. An attempt was made to maximize coverage and integrate as many sources of potential

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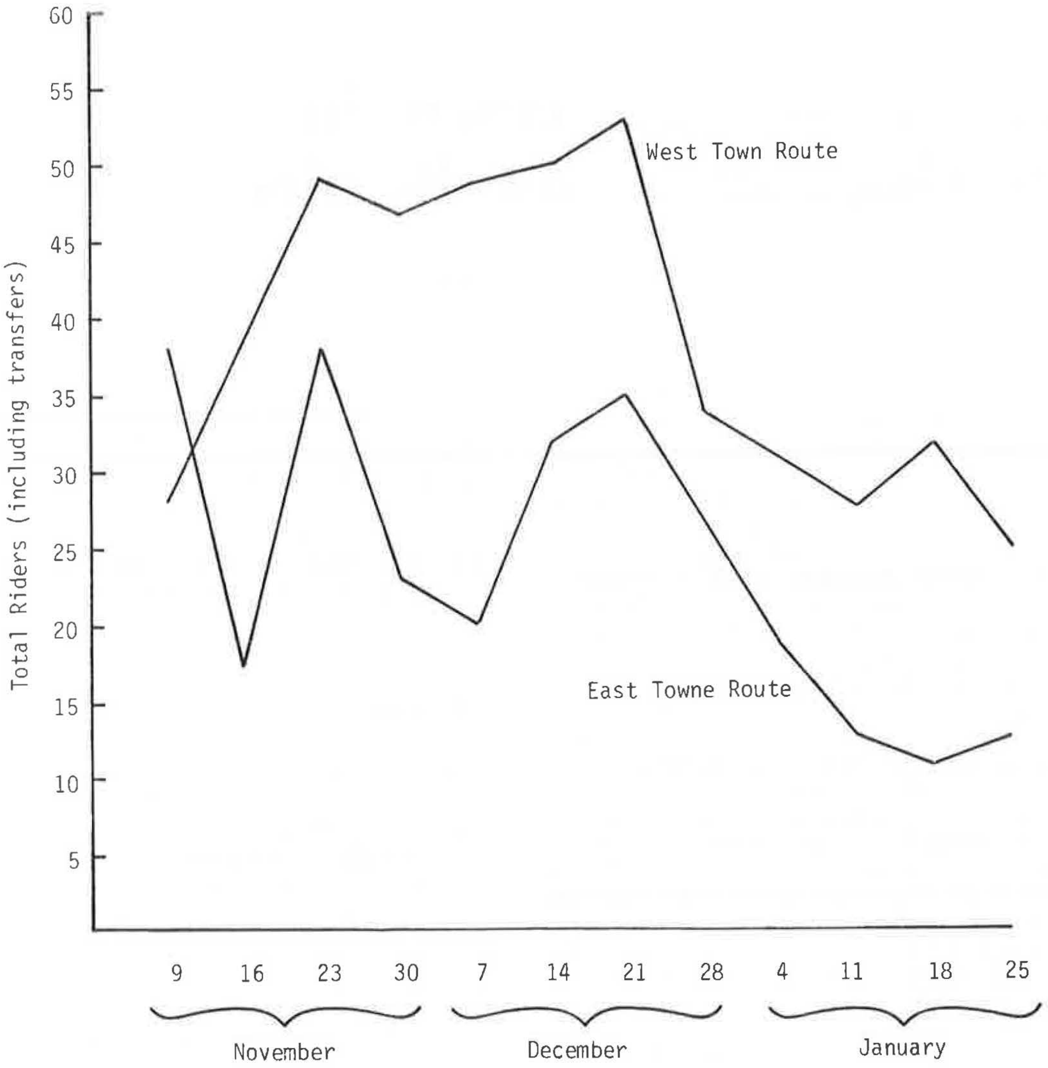

FIGURE 1 Ridership trends.

customers as was feasible within the constraint of the available number of buses and the desired maximum headway. Although portions of these routes were similar to those of some of the regular K-TRANS routes that had operated on Sundays, the new routes did not duplicate any of the previous routes entirely. Although the Shopper's Express service was sponsored by private funds—the management of the two shopping malls—passengers were not restricted from using the service to and from any location along the routes, and they did not have to visit the malls.

The time between the agreements with the mall managements and the beginning of the Shopper's Express service was too short for an elaborate marketing campaign. In addition to reports about the service that were published in local newspapers, the primary promotional effort was the distribution of flyers (or announcements) on the regular buses and at selected sources of potential riders, such as the housing complexes mentioned previously.

SERVICE USE

The new Shopper's Express service was provided for 12 consecutive Sundays. The daily ridership patterns of both routes are depicted in Figure 1. The highest number of boardings on the West Town route occurred on December 21, 1986, which was the Sunday preceding Christmas Day, and the lowest number of boardings occurred on January 25, 1987, which was the last day of service. The pattern of variation of ridership on the East Towne route was slightly different. The highest number of boardings on the East Towne route occurred during the first day of service and again on the third day, both of which were in November. The number of boardings on the Sunday preceding Christmas was slightly lower than those of the highest days in November. The day with the lowest number of boardings on the East Towne route occurred just before the last day. Overall, the West Town route carried 1.6 times as many passengers as the East Towne route.

Monthly ridership records indicated that the total ridership for November was nearly equal that of December. During these 2 months, the West Town Mall route carried an average of 44 riders each Sunday, while the East Towne Mall route carried an average of 29 riders. During January, ridership decreased, and the West Town route carried an average of 29 riders each day, while the East Towne route carried an average of 14 riders each day. By comparison, the average system ridership was 750 boardings per Sunday before the regular service was discontinued.

TABLE 1 SERVICE EFFECTIVENESS MEASURES

	West Town Route		East Towne Route	
Month	Passengers per VMT	Passengers per Round Trip	Passengers per VMT	Passengers per Round Trip
November 1986	0.16	3.3	0.12	2.3
December 1986	0.18	3.8	0.12	2.3
January 1987	0.11	2.3	0.06	1.1
Average	0.15	3.1	0.10	1.9

The 12-Sunday service provided by K-TRANS for the malls operated between 11:00 a.m. and 5:00 p.m. About 33 percent of regular Sunday ridership occurred before 11:00 a.m., which is consistent with 35 percent of service delivered before 11:00 a.m.

The effectiveness of a transit service is usually measured in terms of passengers carried, and in this respect the West Town route was more effective than the East Towne route. Nevertheless, the ridership on both routes was low. Together, the two buses on the West Town route provided 12.5 round trips per day, generating 258 vehicle-miles of travel (VMT). The East Towne route also had 12.5 round trips per day, but its VMT was 240 per day.

It can be noted in Table 1 that even during December, when the ridership was highest, the number of passengers carried (boardings) per VMT on the West Towne route was only 0.18. The value of the indicator "passengers carried per trip" during December was 3.8 passengers per round trip. In other words, there were ~2 passengers per one-way bus trip on the West Town route. On the East Towne route, on the average, there was only 1 passenger per one-way bus trip during November and December 1986.

If an average of 750 boardings per Sunday is used, it can be estimated that 503 boardings would have been served by the regular Sunday service during the time the mall service was operated. Given that the November–January period reflects average ridership on the K-TRANS system, it is clear that the contract service, with an average of 63 boarding per Sunday, served only a small percent of the previous ridership market. On a systemwide level for an average Sunday, K-TRANS previously served 0.61 passengers per vehicle-mile, or 0.46 full-fare paying passengers per vehicle mile, or 7.1 passengers per round trip. These statistics represent a level of use more than twice that experienced by the new service.

A general review of Sunday ridership characteristics indicates that the contract service to the two malls provided service to only a portion of the Sunday bus market. Operating during 6 of the previous 8 hours of service and providing 38 percent coverage of the previous 1,382 vehicle-miles of service, the replacement service was not able to capture a proportionate fraction of the ridership. The new service, which focused on the two malls, basically served the mobility needs of Sunday shoppers. This aspect is discussed in the next section.

CHARACTERISTICS OF RIDERS AND THEIR TRAVEL

On-Board Bus Survey

Information on the characteristics of riders and their trips was gathered from an on-board survey that was performed on three Sundays during the 3-month operation of the bus service. During the survey, 117 people were contacted while they were riding the buses on the West Town and East Towne routes. Among these 117, 77 individuals responded to all the questions. Of these, 40 were found to have been previously interviewed that day. They were asked only about their purchases at the mall and suggestions for improving the service.

During January and February 1986 (that is, earlier that same year), an on-board ridership survey of K-TRANS regular service had been done as part of a transit improvement study performed jointly by K-TRANS, the Metropolitan Planning Commission, and consultants. This earlier survey, which included Sunday service, provided the opportunity for a comparison of the regular and replacement services through the findings of the two surveys.

Age and Sex

Information on the demographic characteristics of the riders of the replacement Sunday service (Shopper's Express) is presented in Table 2, which also includes information on the regular Sunday service. The age group that included the largest proportion of riders of the replacement service is 31 to 39 years (41 percent). In contrast, people 15 to 30 years of age made up the largest proportion (50 percent) of the regular Sunday service. Senior citizens (i.e., people 65 years of age or more) made up nearly the same proportion among both groups of riders: 14 percent for replacement service and 12 percent for regular service.

The male-female ratios among the bus riders were similar for both Sunday services. The proportion of females was 58 percent for the replacement Sunday service and 55 percent for the regular Sunday service.

TABLE 2 SUNDAY USER CHARACTERISTICS

	Proportion of Users (%)	
Characteristics	Replacement Service	Regular Service
Age (years)		
14 and younger	1	5
15–30	28	50
31–59	41	30
60–64	16	3
65 or older	14	12
Sex		
Male	42	45
Female	58	55
Race		
White	73	53
Black	27	43
Other	0	4

TABLE 3 TRANSIT DEPENDENCY OF SUNDAY SERVICE RIDERS

	Proportion of Users (%)	
Characteristics	Replacement Service	Regular Service
Vehicle Ownership		
No car	81	66
One car	16	23
Two or more cars	3	11
Driver's License		
Have	48	43
Do not have	52	57

TABLE 4 ALTERNATIVE MODES OF TRAVEL ON SUNDAY

Alternative	Proportion of Respondents (%)
None (could not make the trip this day)	72
Ride with someone	9
Drive own vehicle	0
Taxi	13
Walk	6
Other	0

Transit Dependency

Several of the survey questions were intended to determine how dependent the passengers were on public transportation. Three of these questions focused on the availability of alternative modes of travel and on driving ability. The first of these three concerned automobile ownership. As presented in Table 3, 81 percent of the replacement service riders did not have a vehicle in operating condition. The next question, directed to the remaining 19 percent (who had vehicles), asked whether they could have used a vehicle for the trip that they were making on the bus. In their replies, 79 percent of the car owners said that they could not have used their vehicles. Thus, on the basis of responses to these two questions combined, 96 percent of the riders could not have used a private vehicle for their travel and may be considered "captive" riders.

The corresponding information about the users of the regular Sunday service is also presented in Table 3. It can be observed that these riders had more mobility, given that the proportion of riders without automobiles was 66 percent. The proportion of captive riders among the users of regular Sunday service, on the basis of both vehicle ownership and vehicle availability, was 85 percent.

The third transit dependency question determined whether the riders possessed a currently valid driver's license or not. As Table 3 indicates, 52 percent of the users of the replacement service did not have a valid driver's license. In this respect, the users of the regular Sunday service were not significantly different.

The riders were also asked how they could have made the trip for which they were using the bus if the service had not been provided (Table 4). It was found that 72 percent of the respondents would not have made the trip. Among the alternative modes of travel that could have been used by some of the riders, taking a taxi and "riding with someone" were mentioned most frequently. Those who would not have made the trip were further asked if they would have made the trip on some other day instead of Sunday, and 75 percent of them answered "yes." By combining the responses of these two questions, it may be concluded that ~18 percent of the respondents would not have made their trips without the replacement bus service.

Trip Purpose

One question sought information on why the riders were using the replacement bus service on Sundays. The results are presented in Table 5, which also includes comparable statistics for the regular Sunday service.

Although the replacement service was sponsored by the shopping malls, the riders were not restricted from traveling to other locations along the routes. Furthermore, although the sponsors were primarily interested in attracting shoppers, the service could have served other purposes as well. The results indicate that 68 percent of the trips/rides were for shopping. It is interesting to note, however, that 32 percent of the trips made on Shopper's Express service served other purposes. Work trips, for example, constituted 16 percent of the total. In addition, not all shopping trips were to the malls; 10 percent of all trips were for shopping at other locations. The analysis of boardings and alightings at different bus stops also confirmed that a substantial proportion of trips were not aimed at the malls.

It should be noted that, as might have been expected, the replacement Sunday bus service did not serve many trips made for religious purposes. In fact, only one trip was reported to have a religious purpose. Although no such information was available from the regular Sunday bus service survey, a separate survey performed in 1985 by the Knoxville Commuter Pool indicated that nearly a third of the Sunday bus trips were related to church. The starting time of the Shopper's Express service was 11:00 a.m., and the routes were not designed to serve churches.

TABLE 5 SUNDAY TRIP PURPOSE

Trip Purpose	Replacement Service (%)	Regular Service (%)
Work	16	29
Shop	68	38
At mall	58	
At other stores	10	
Medical	0	2
Social/recreation	8	7
Other	8	29
Religious	1	
Miscellaneous	7	

Other Related Travel Modes

The use of a fixed-route, fixed-schedule bus service often requires the use of other modes of transportation to and from transit stops. Other methods of travel are also sometimes needed to complete a portion of a trip circuit, such as the "return" or "beginning" portion of a round trip. Most of the replacement service riders (91 percent of the interviewees) walked to their bus stops. Also, as might have been expected, most of the replacement service riders (78 percent) used the bus service for both the beginning and return legs of their round trips. For the replacement service, this proportion was much higher than that for the regular Sunday service (58 percent). It is interesting to note that several people (16 percent for the replacement service and 31 percent for the regular service) used private automobiles and taxis for one of the legs of their round trips.

Previous Use of Sunday Bus Service

The survey revealed that 79 percent of the replacement service users had used the regular Sunday bus service before it was discontinued. From responses to inquiries about the frequency of regular Sunday service use, it was determined that, on the average, previous users had used the bus on three Sundays during October 1986 (the last month of regular service). This clearly indicated that the majority of the replacement service users were regular users of the discontinued service.

COST-EFFECTIVENESS ANALYSIS

The actual cost of operating the Shopper's Express service by K-TRANS on Sundays was about $20 per bus-hour of service. This unit cost included driver's wage; fuel, oil, and other supply costs; and some maintenance expenses. The drivers who worked the Sunday service were extra board operators, and they were paid at regular ("straight time") rates.

On each Sunday the four buses used for the Shopper's Express provided 24 bus-hours of service, for which the K-TRANS costs were ~$480. The shopping centers' management paid a fee of $30 per bus-hour, which generated K-TRANS a revenue of $720 for each Sunday. K-TRANS thus earned a profit of $240 per Sunday for the new service. Before its discontinuation, the regular K-TRANS Sunday bus service cost ~$3,000 per day and generated a revenue of only $300 per day. Thus K-TRANS previously lost ~$2,700 each Sunday.

Because of the nature of the arrangement with the two shopping centers, K-TRANS' revenue did not depend on the level of ridership. The revenue generated by the riders, however, did help offset the costs incurred by the management of the two malls. Each management had made an advance commitment to pay K-TRANS a fixed fee of $360 for each day's service, and it was agreed that the farebox revenues from each route would be credited to the respective mall managements.

During December 1986, the West Town route carried an average of 41 revenue passengers and 6 transfers per day, for a total of 47 riders per day. The revenue generated was thus only $20.50 per day, and the net cost was $339.50 per day. The West Town Mall management thus had to pay $7.22 for each rider coming to the mall. These cost data are presented in Table 6, along with similar data for November 1986 and January 1987.

Ridership on the East Towne route was lower than that on the West Town route, and the net cost per day incurred by the East Towne management in December was $348 per day. This cost corresponds to $12 per rider coming to the mall. The ridership was lowest during January 1987, so the cost per rider was $25.32—the largest cost recorded.

The assessment of the cost-effectiveness of the Sunday service from the standpoint of the management of the shopping centers would require information not only on the net costs but also on the dollar amount of purchases that the riders made at the stores. To obtain this information, the on-board survey included a direct question about the purchases and expenditures that riders made in the malls. On the basis of the answers, it was determined that, on the average, Sunday bus riders to the West Town Mall spent $34.50 per person for food and nonfood purchases. On the average, riders to East Towne Mall indicated that they spent $24.00 per person for food and nonfood purchases. Whether this expenditure level would justify the cost of providing the service depends on other factors, such as the type of purchase and the associated profit margin.

On the basis of information provided by the management of East Towne Mall, all shoppers on the average spend $38.79 on nonfood purchases and $4.50 on food items per visit to the mall, for a total of $43.29. The shoppers in this average include those who do not spend any money at all. When these purchase amounts are compared with those reported by the replacement service riders (Table 7), it is evident that the transit patrons spent less than the average shopper.

TABLE 6 COSTS INCURRED BY MALL MANAGEMENTS

Month	Farebox Revenue per Day ($)	Net Cost per Day ($)	Net Cost per Rider ($)[a]
West Town Route			
November 1986	19.00	341.00	8.32
December 1986	20.50	339.50	7.22
January 1987	13.00	347.00	11.79
East Towne Route			
November 1986	13.50	346.50	11.95
December 1986	12.00	348.00	12.00
January 1987	5.50	354.50	25.32

[a] Including transfer.

TABLE 7 PURCHASES AT MALLS

Amount of purchase ($)	West Town Mall	East Towne Mall
1–10 (Avg. 5)	11	10
11–25 (Avg. 17.50)	6	6
26–50 (Avg. 37.50)	8	2
51–100 (Avg. 75)	4	4
101–300 (Avg. 200)	1	0
	29	22
Average purchase per rider	$34.50	$24.00

As noted earlier, not all the Shopper's Express riders went to the malls. Even among those who did, some went for reasons other than shopping. In fact, only 68 percent of the replacement service riders went to the malls primarily to shop. In addition, as reported earlier, some of the Sunday service riders would have made their trips on a weekday if the replacement service had not been provided.

When the factors described in this section are considered, especially the small number of shoppers using the replacement service and the lower than average expenditures made by the riders, it is understandable that the tenants of the malls themselves were not willing to participate financially in this management-sponsored venture.

CONCLUSIONS

The Sunday replacement bus service in Knoxville was initiated as a public service by two private organizations: the managements of East Towne and West Town malls. The two managements contracted K-TRANS to provide this service for 12 Sundays during the November-December holiday season. The service was intended to serve two major purposes: to respond to an emotional public issue involving a community need and to stimulate business at the malls. It was not expected that the service would be financially profitable, but it was hoped that the service might "break even" financially. The magnitude of the actual losses was not expected, however, and the low rate of use was a disappointment to the mall sponsors, K-TRANS, and community leaders.

A possible explanation for the lack of rider response may be that the service was not a true replacement for the discontinued Sunday K-TRANS service. The mall-sponsored service was a Shopper's Express, operated to coincide with mall business hours, and the routes were structured to serve major housing complexes and the two malls.

The replacement service carried an average of 62.5 boardings per day and 750 boardings during its entire tenure of 12 days, whereas the regular K-TRANS Sunday service carried ~750 boardings per day. Some of these riders were previous Sunday bus users who used the service to reach destinations other than the mall. Although the two mall routes represented 38 percent of the previous Sunday route coverage and attempted to serve major transit-dependent housing units, the destinations of many of these Sunday riders were not accessible with the new service. Systemwide VMT per day decreased by 64 percent, from 1,382 to 498 vehicle-miles per day. The ridership decreased by 78 percent, so that the average decline in use was from 0.61 to 0.13 boardings per vehicle-mile.

In addition to the obvious differences in coverage and service hours, the replacement service was hampered by

- A route structure and fare schedule not familiar to former users;
- Inadequate time for a vigorous marketing effort in addition to the distribution of flyers;
- Lack of follow-up promotions by mall merchants; and
- Lack of a commitment to extend the service beyond the end of January.

The on-board surveys indicated that the privately sponsored Sunday service attracted transit dependents: 96 percent of the riders could be so classified. The major purpose of travel, as expected, was shopping (68 percent of trips). A large proportion of the riders were elderly; 30 percent of riders were more than 60 years old. Those who were not attracted by the replacement service include the young (55 percent of previous K-TRANS riders were 30 years or younger) and people traveling for work or religious purposes.

It is notable that 82 percent of the riders said that they could have made the trip at another time, no doubt because most of them were going shopping. Shopping trips are different in this regard from travel for work or appointments, in which postponement of activities and travel to other days is not usually an option.

Basically, the privately sponsored Sunday Shopper's Express service did not attract new Sunday riders. Even at the peak of the holiday season, the bus served primarily previous Sunday riders. Because of its limited route structure, however, the replacement service was only able to serve a portion of Sunday mobility needs. It also attracted segments of the market, such as elderly shoppers, who have flexibility in selecting alternative times of travel. In summary, the privately sponsored service never provided an effective replacement for regular Sunday K-TRANS service and was not able to attract its own clientele.

The managements of both East Towne and West Town Malls must be praised for their concern for the community and support of public transit. The public-private partnership molded by this experiment may serve as a model for future efforts. Given declining public financial support for transit and the inability of transit management to easily alter routings and schedules to reflect changing land uses and transit demands, it is important to attract private support and resources. Public-private partnership opportunities should be explored for extending public transit services to special traffic generators that have developed beyond the existing transit routes.

The Sunday Shopper's Express experiment in Knoxville highlights the difficulty of achieving efficient use of resources in attempts to serve a stratified transit market during periods of low ridership. The concept of a system with access to an array of destinations is important in meeting the mobility needs of a diverse group of riders.

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

Optimal Design of Transit Short-Turn Trips

AVISHAI CEDER

A set of procedures is presented for efficiently designing transit timetables with trips that are initiated beyond the route departure point, or terminated before the route arrival point, or both ("short-turn trips"). In practice, transit frequency is determined at the route segment with heaviest load, whereas at other segments the operation may be inefficient because of partial loads (empty seats). Transit schedulers attempt to overcome this problem by manually constructing short-turn trips to reduce the number of vehicles required to carry out the transit timetable. The study presented herein was meant to improve and automate this task by identifying feasible short-turn points, deriving the minimum fleet size required by a given schedule, and adjusting the number of departures at each short-turn point to that required by the load data (provided that the maximum headway associated with passenger wait time is minimized). Other objectives included minimizing the number of short-turn trips while ensuring that the minimum fleet size is preserved and creating vehicle schedules (blocks). A simple example is used throughout to illustrate the procedures developed.

The first phase of this research, which has been completed and documented (*1*, *2*), provides procedures for using passenger load data to derive alternative timetables along an entire transit route, without short-turn trips. A short-turn trip begins beyond the route departure terminal or is terminated before the route arrival terminal, or both. The possibility of generating short lines permits further saving of vehicles while ensuring that the passenger load in each route segment will not exceed the desired occupancy (load factor).

Schedulers at most transit properties usually include the short-turn operating strategy in their efforts to reduce the cost of service. The procedures commonly used are based only on visual observation of the load profile, that is, the distribution of the loads along the entire route. A potential turn point is determined at the adequate time point (major stop) nearest to the stop at which a sharp decrease or increase in the passenger load is observed. Although this procedure is intuitively correct, the schedulers do not know if all the short-turn trips are actually needed to reduce the fleet size. Unfortunately, each short-turn trip limits service and hence tends to reduce the passenger level of service.

Furth et al. (*3*) presented an overview of operating strategies on major downtown-oriented bus routes. Among the strategies discussed were short-turn trips, in which the service trip begins farther along the route, but the arrival point of all the trips is the same. The present work designates all the possible categories of short-turn trips for any type of transit lines (crosstown routes, downtown-oriented routes, feeder routes, etc.).

The major objectives set forth herein are as follows:

- To identify feasible short-turn points based on passenger load profile data;
- To derive the minimum fleet size required to carry on a given timetable (including the consideration of deadheading, i.e., nonrevenue trips);
- To adjust the number of departures at each short-turn point to that required by the load data, provided that the maximum headway to be obtained is minimized (this objective results in the maximum possible short-turn trips and the minimum required fleet size);
- To minimize the number of short-turn trips, provided that the minimum fleet size is maintained (for a given timetable, this objective results in increasing the level of service seen by the passengers); and
- To create vehicle blocks for the final derived timetable (a block is a sequence of revenue and nonrevenue activities for an individual vehicle).

To satisfy these objectives, several methods were developed. These methods are based on procedures and algorithms that use data commonly inventoried or collected by most transit properties. Furth (*4*) uses origin-destination (O-D) data to assess short-turn strategies for route 16 in Los Angeles (SCRTD) between West Hollywood and downtown. Although use of O-D data can improve the scheduling of short-turn trips, this information is not commonly available at transit agencies. The current work is not based on O-D data, but its methods can be extended to include such data whenever they are available.

APPROACH AND BACKGROUND

Framework

The initial information required for constructing the short-turn trips includes

- A complete timetable for each route timepoint;
- Passenger loads for each time period across all timepoints;
- Minimum frequency or policy headway; and
- A set of candidate short-turn points.

This information is given for both route directions (each direction requires its own data). The complete timetable can be

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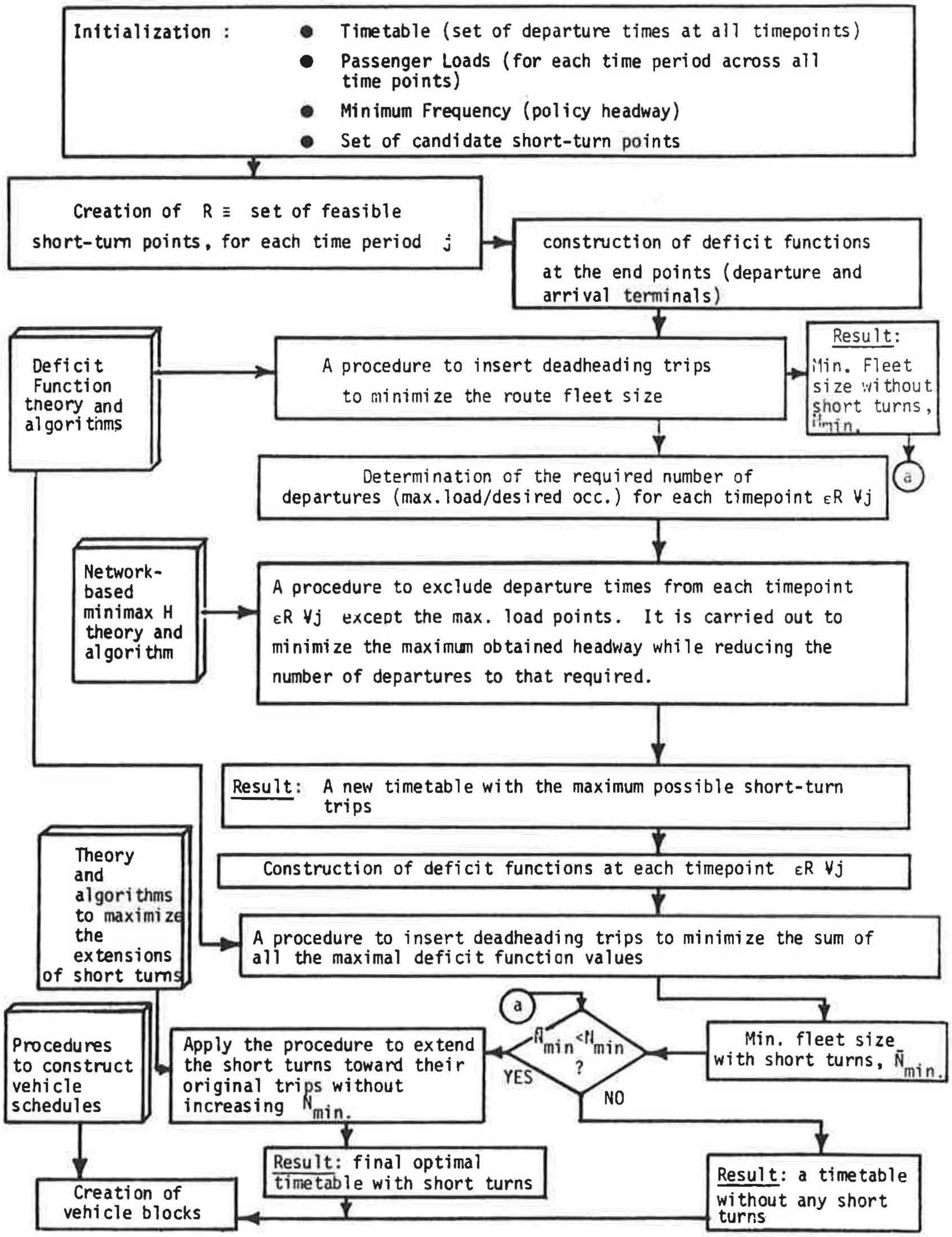


FIGURE 1 Flow chart describing the design of transit timetables and vehicle schedules with short turns.

provided by the scheduler or may be derived from the passenger load information (*1, 2*). Candidate short-turn points are usually all the major route stops (timepoints) at which a public timetable is posted. In some cases, the scheduler may limit the candidate points to only those timepoints at which the vehicles can actually turn back.

The overall program to accomplish the objectives of this work is presented in flowchart form in Figure 1. It starts with a procedure to determine the set of feasible short-turn points, R_j, among the candidate points. Then the deficit function theory, as explained below, is used to derive the minimum number of vehicles required to carry out all the trips in the complete two-direction timetable, $N_{\min}$. The required number of departures is determined at each feasible short-turn point, and then the so-called minimum H algorithm is applied. The basis of the algorithm is the elimination of some departures from the complete timetable to obtain the number of departures required. In that procedure, the algorithm minimizes the maximum difference between two adjacent departure times (headway). At this stage, as shown in Figure 1, the deficit function method derives the minimum required fleet size with short turns, $\overline{N}_{\min}$. If this minimum is less than the size required without short turns, then another procedure is applied. This second procedure inserts the maximum possible departures back among those previously eliminated, provided that the minimum fleet size, $\bar{N}_{\min}$, is maintained. The final step of the overall program is to create vehicle blocks to cover all the trips that appear in the last version of the two-direction timetable.

Deficit Function: Background

The deficit function approach for assigning the minimum number of vehicles to carry out a given timetable can be described as follows. A deficit function is simply a step function that increases by one at the time of each trip departure and decreases by one at the time of each trip arrival. Such a function may be constructed for each terminal in a multi-terminal transit system. The only information needed to construct a set of deficit functions is the transit timetable.

The main advantage of the deficit function is its visual nature. Let $d(k, t)$ denote the deficit for point k at time t. This point k can be either a terminal or a timepoint, provided that some trips are initiated or terminated (or both) at this point. The value of $d(k, t)$ represents the total number of departures less the total number of trip arrivals up to and including time t. The maximal value of $d(k, t)$ over the schedule horizon is designated $D(k)$.

It is possible to partition the schedule horizon of $d(k, t)$ into a sequence of alternating hollow and maximal intervals. The maximal intervals define the interval of time over which $d(k, t)$ takes on its maximum value. A hollow interval is defined as the interval between two maximal intervals. Hollows may consist of only one point, and if this case is not on the schedule horizon boundaries, the graphical representation of $d(k, t)$ is emphasized by a clear dot.

If the set of all the route and points (terminals or timepoints) is E, the sum of $D(k)$ for all $k \in E$ is equal to the minimum number of vehicles required to service the set E. This is known as the fleet size formula, independently derived by Bartlett (*5*), Gertsbach and Gurevich (*6*), and Salzborn (*7, 8*). Mathematically, for a given fixed schedule:

$$N = \sum_{k \in E} D(k) = \sum_{k \in E} \max_{t} d(k, t) \tag{1}$$

where N is the minimum number of vehicles required to service the set E.

When deadheading (DH) trips are allowed, the fleet size may be reduced below the level described in Equation 1. Ceder and Stern (*9*) describe this procedure in the construction of a unit reduction deadheading chain (URDHC). Such a chain is a set of nonoverlapping DH trips that, when inserted into the schedule, reduces the fleet size by one. The procedure continues to insert URDHCs until no more can be inserted or until a lower bound on the minimum fleet size is reached. [determination of the lower bound is detailed in the work of Stern and Ceder (*10*)]. The deficit function theory for transit scheduling is extended by Ceder and Stern (*11, 12*) to include possible shifting in departure times within bounded tolerances.

INITIAL PROCEDURES

Feasible Short-Turn Points

The short-turn points are usually route timepoints at which the vehicle can turn back without interfering with the traffic flow. It is therefore anticipated that for each route the initial set of candidate short-turn points is given by the scheduler.

Let the set of candidate short-turn points be designated as set R_1 for one direction and R_2 for the opposite route direction. Note that R_1 does not necessarily coincide with R_2. More specifically,

$$R_1 = \{r_{11}, r_{12}, \ldots, r_{1n}\} \tag{2}$$

$$R_2 = \{r_{21}, r_{22}, \ldots, r_{2q}\} \tag{3}$$

where r_{ij} is the jth candidate short-turn point in the direction

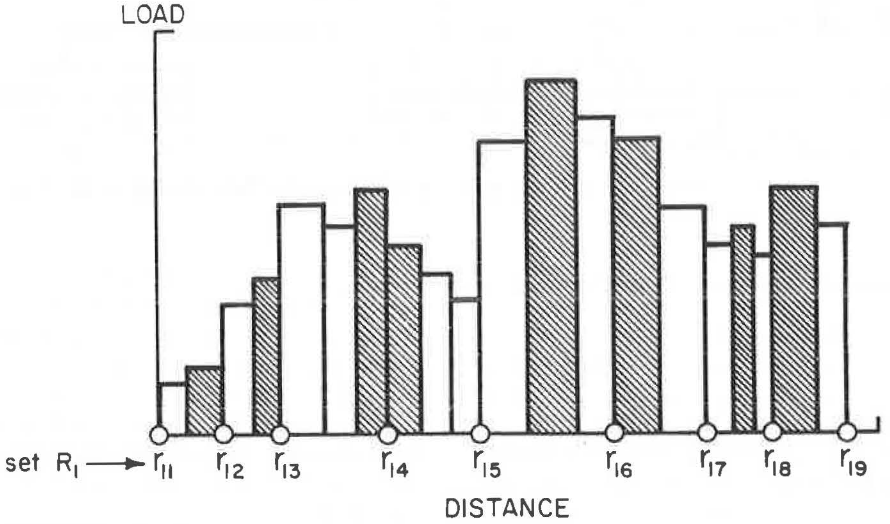


FIGURE 2 Load profile for direction 1 and a given time period in which the short-turn points r_{15} and r_{18} are redundant.

($i = 1, 2$) and there are n and q such points for directions 1 and 2, respectively.

For a given time period, the fluctuation of a passenger load along the entire route (load profile) may reveal that some short-turn points are actually redundant. For example, consider a load profile that consists of 20 stops and 9 candidate short-turn points, as shown in Figure 2. Theoretically, each segment between two adjacent short-turn points can be treated independently with respect to its required frequency. This frequency is determined by the maximum observed load in the segment, which is marked by a hatched area in Figure 2. In the short-turn strategy, however, all the trips must serve the heaviest load segment of the route (in the example, all trips must cross the r_{15}-r_{16} segment). Hence fewer trips are required between r_{14} and r_{15} than between r_{13} and r_{14}, while the latter group of trips must cross the r_{15}-r_{16} segment. Consequently, the point is redundant. The same argument also holds for r_{18}, which is located after the max load segment.

The exclusion of the redundant points at each time period j results in a set of feasible short-turn points, R_j, and this analysis is important from the computational time viewpoint. In the formal description of the algorithm, there is an additional analysis of the difference between the required frequency at the short-turn point associated with the max load segment and a considered short-turn point. If this difference is small, the short-turn point under consideration can be deleted. The limit on this difference can be determined by the scheduler; otherwise, it is automatically set to 1.0. Note that the difference in the frequencies is equivalent to the difference in the load, and there are always stochastic variations in that load. Hence, if this difference is small, it is not reasonable to consider short-turn trips from the associated short-turn point. This procedure is similar to the manual procedure performed in current practice, where the scheduler selects the short-turn points on the basis of observed sharp increase or decrease in the load on the load profile.

Finally, for subsequent analyses, the union of all R_j for all time periods j is denoted set R, or mathematically, $\cup R_j = R \; \forall j$.

Minimum Fleet Size for Complete Timetable: Example

The deficit function theory described in the previous section is used to determine the minimum number of vehicles required to cover the complete timetable without short-turn trips. This minimum size is designated $N_{\min}$, as shown in Figure 1.

A simple example is used to illustrate the deficit function approach and the procedures developed. This example, which is given in Figure 3, is also used in the work of Ceder (*13*). It is based on a timetable that covers a schedule of about 2 hr (these hours refer to the departure times at the maximum load points). The route (set R) includes three timepoints (A, B, C), and the average travel times for service and deadheading trips are given in Figure 3.

By using the deficit function approach as a basis, it is possible to construct $d(A, t)$ and $d(C, t)$. The minimum number of vehicles required, without deadheading trips, is $D(A) + D(C) = 11$. However, a DH trip can be inserted from A to C, departing after the last maximal interval of $d(A, t)$ and arriving just before the start of the first maximal interval of $d(C, t)$. Both $d(A, t)$ and $d(C, t)$ are then changed, according to the dashed line in Figure 3. $D(C)$ is reduced from 6 to 5, and the overall fleet size is reduced from 11 to 10. After that, it is impossible to reduce the fleet size any farther through DH trip insertions; hence, $N_{\min} = 10$. This condition can also be detected automatically by the lower bound test. The simple lower bound, 10, is equal to the maximum value of the combined function (with respect to the time): $d(A, t) + d(C, t)$. From the DH trip insertion procedure, the maximum of the combined functions is 10, and therefore $N_{\min}$ reaches its lower bound. An improved lower bound method appears elsewhere (*11*).

PROCEDURE TO EXCLUDE DEPARTURE TIMES: MINIMAX *H* ALGORITHM

Establishing Level-of-Service Criterion

The basic information required for considering short turns is the load profile along the entire route. These data are available at most bus properties worldwide and are called ride check information (loads and running times along the entire route). On the basis of this load profile information, each route segment between two adjacent short-turn points can be treated separately. That is, the required number of trips between the $(k-1)$th and kth short-turn points for a given direction and time period is:

$$F_m = \max (P_k/d, F_{\min}) \tag{4}$$

where P_k is the maximum load observed between the two adjacent short-turn points, d is the desired occupancy (load standard), and $F_{\min}$ is the minimum required frequency (the reciprocal of what is known as the policy headway).

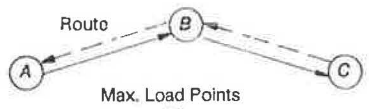
In current practice the complete timetable is based on the maximum load, P_m, observed along the entire route in a given time period. If the frequency determined from this max load is not based on the policy headway, then its formulation is

$$F_m = P_m/d \qquad P_m = \max_k P_k \tag{5}$$

The manual procedure performed by the scheduler to create short-turn trips is simply exclusion of departure times to set the frequency at each short-turn point k to F_k instead of F_m. The exclusion of departure times is usually performed without any systematic instructions, in the belief that by doing so, it is possible to reduce the number of vehicles required to carry out the timetable.

The result of excluding certain departure times is that some passengers will have to extend their wait at the short-turn points. To minimize this adverse effect, it is possible to set the following (minimum H) criterion: "Delete $F_m - F_k$ departure times at k with the objective of minimizing the maximum headway obtained."

It is known that in a deterministic passenger arrival pattern, the wait time is half the headway. Therefore the minimum H criterion attempts to achieve the minimization of maximum wait. This criterion is called "minimax H," and it can represent an adequate passenger level of service whenever the scheduler's strategy allows elimination of some departure times.



Direction	A - C			C - A			
Time-point	A	B	C	C	B	A	
	7:00	7:15	7:40	7:00	7:20	7:35	
7 - 8	7:10	7:25	7:50	7:15	7:35	7:50	
	7:25	7:40	8:05	7:20	7:40	7:55	7 - 8
at B	7:35	7:50	8:15	7:25	7:45	8:00	
	7:40	7:55	8:20	7:30	7:50	8:05	at C
	7:45	8:05	8:30	7:40	8:00	8:15	
8 - 9	7:50	8:10	8:35	7:50	8:10	8:25	
	8:00	8:20	8:45	8:05	8:30	8:45	
at B	8:15	8:35	9:00	8:15	8:40	8:55	8 - 9
	8:25	8:45	9:10	8:20	8:45	9:00	at C
	8:40	9:00	9:25	8:27	8:52	9:07	

Hours at max. load point	Travel times (min.)				DH times (min.)		
	A - B	B - C	C - B	B - A	A - C	A - B	B - C
7 - 8	15	25	20	15	25	15	5
8 - 9	20	25	25	15			

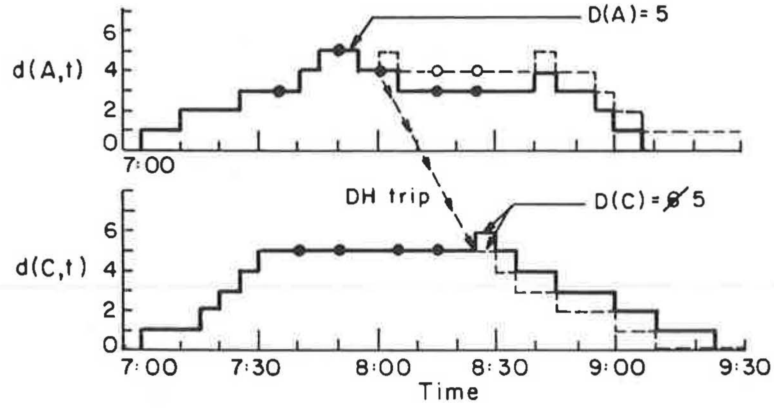


FIGURE 3 Example of a 2-hr two-way schedule for which 10 vehicles are required (based on the graphical deficit function method).

Minimax *H* Algorithm

To solve the optimization problem with the minimax *H* criterion, a theory was developed by Ceder (*14*) on the basis of the representation of the problem on a directed network with a special pattern, application of a modified shortest-path algorithm on the network to determine the minimax headway, and application of an algorithm to ensure that the exact number of required departures will be included in the optimal solution. The minimax *H* algorithm will now be outlined and applied to the example problem presented in Figure 3.

Let $G_m = \{N_m, A_m\}$ be the special network, consisting of a finite node set N_m and a finite set A_m of directed arcs. A general illustration of the special network, accompanied by an example, is presented in Figure 4. In general, n departures are given from the complete timetable, and it is required that only $m < n$ will remain while satisfying the minimax *H* criterion. The construction of G_m is based on $m - 2$ equally spaced departure times between the first and last given departures, t_1 and t_n, respectively. These equally spaced departure times are denoted by $t'_2, t'_3, \ldots, t'_{m-1}$ and have the equal headway of $t_e = (t_n - t_1)/(m - 1)$. The G_m network has the following six characteristics:

- G_m consists of m rows. The first and last rows are only nodes t_1 and t_n, respectively, and there is a row for each t'_j, $j = 2, 3, \ldots, m - 1$.
- Each node in N_m represents a departure time in the given set of departures; however, it is not necessary that all the given departures be included in N_m (see 7:10 and 8:50 in the

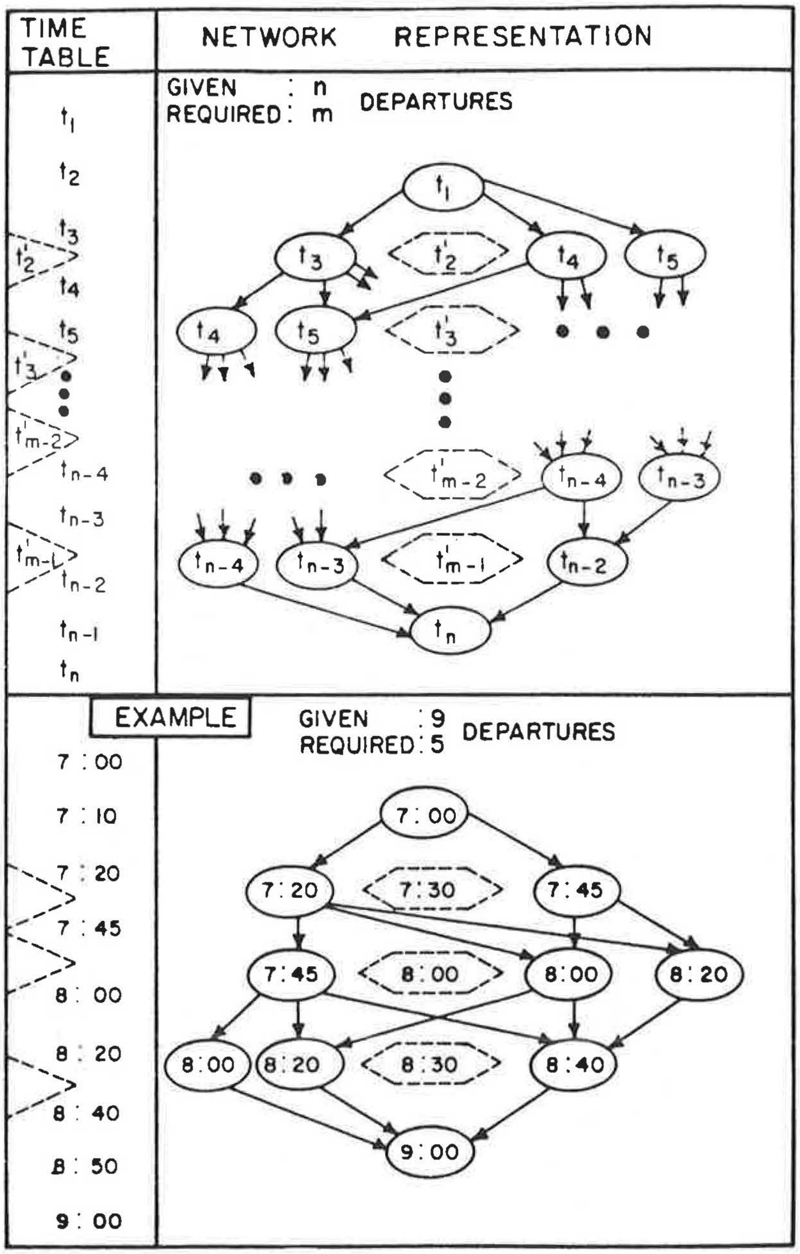


FIGURE 4 General network representation of a given timetable at one location and an example of this network construction approach.

example in Figure 4). Also, the same departures may be represented by several nodes (see 7:45, 8:00, and 8:20 in Figure 4).

- The nodes in each row are organized in increasing time order from left to right with respect to their associated t'_j. That is, all given nodes t_i such that $t'_k \leq t'_j < t'_{k+1}$ are positioned twice, to the right of t'_k and to the left of t'_{k+1}, where t'_k, t'_{k+1} are two adjacent, equally spaced departure times. An exception is that in the second and the $(m - 1)$th rows, only one node is positioned to the left of t'_2 and to the right of t'_{m-1}, respectively. These single nodes, t_3 and t_{n-2} in Figure 4, are selected such that t_3 is the node closest to t'_2, provided that $t'_2 < t'_3$, and t_{n-2} is the node closest to t'_{m-1}, provided that $t'_{m-1} \leq t_{n-2}$.
- The directed arcs in A_m connect only nodes from the kth row to the $(k + 1)$th row, where $k = 1, 2, \ldots, m - 1$.
- A directed arc from t_i to t_j is included in A_m if $t_j > t_i$. An arc from t_i to t_i is included if and only if without this arc, G_m is disconnected.
- The length of an arc from t_i to t_j is exactly $t_j - t_i$.

After constructing G_m, a modified shortest-path algorithm is applied. This is a modified version of the efficient algorithm initially proposed by Dijkstra (*15*). The Dijkstra method is based on assigning temporary labels to nodes. The label on the node is an upper bound on the path length from the origin node to that node. These labels are then updated (reduced) by an iterative procedure. At each iteration, exactly one of

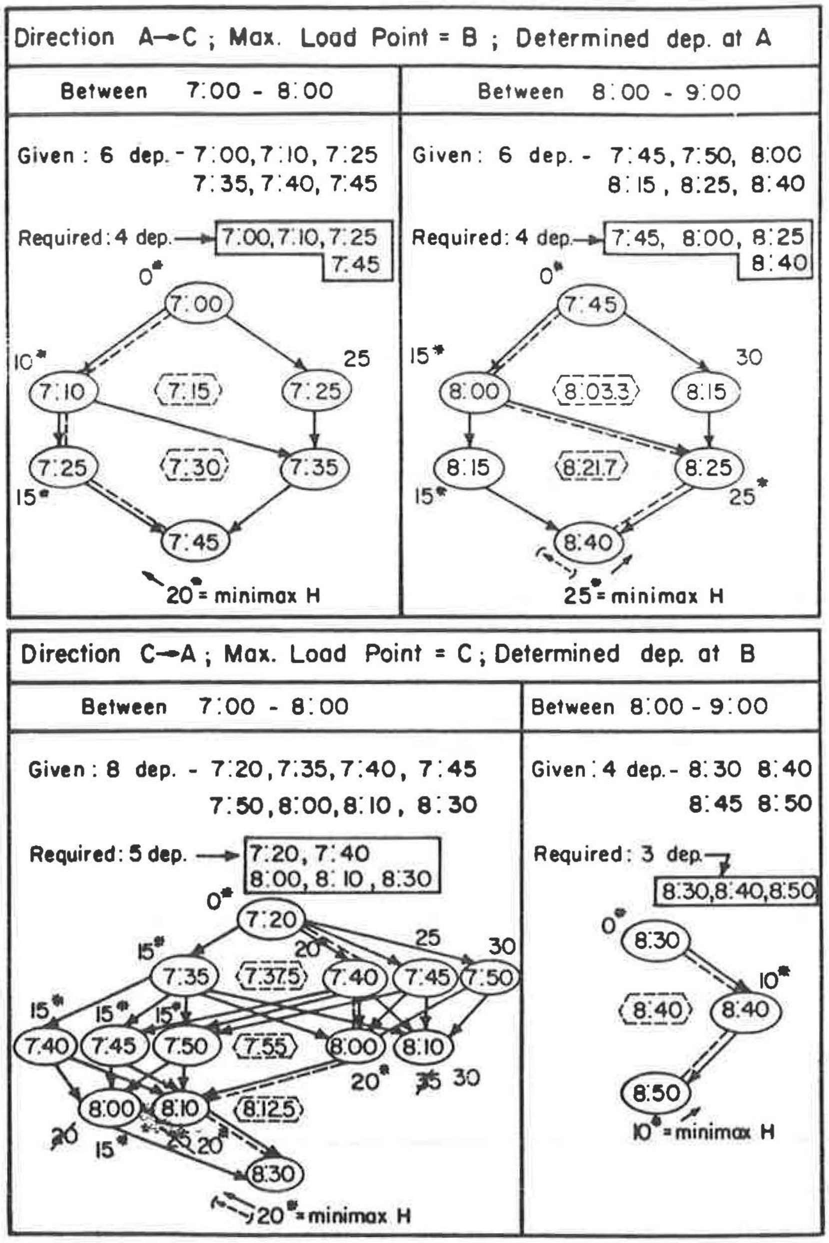


FIGURE 5 **Minimax *H* algorithm for the example problem.**

the temporary labels becomes permanent, implying that it is no longer the upper bound but rather the exact length of the shortest path from the origin to the considered node.

The modification of the Dijkstra method is in the computation step in which the labels are updated. It is modified from

$$\pi(t_i) = \min \left[\pi(t_i),\ \pi^*(t_k) + (t_i - t_k)\right] \tag{6}$$

to

$$\pi(t_i) = \min \{\pi(t_i),\ \max \left[\pi^*(t_k),\ (t_i - t_k)\right]\} \tag{7}$$

where $\pi(t_i)$, $\pi^*(t_k)$ are temporary and permanent labels of nodes t_i and t_k, respectively. This algorithm is applied to G_m where the origin node is t_1, and the algorithm terminates when the temporary label on node t_n becomes permanent.

The third part of the minimax *H* algorithm ensures that the optimal result will include exactly the required *m* departures. Although the modified shortest-path algorithm on G_m determines the value of the minimax headway, it does not ensure that the result will include all *m* required departures. The detailed description of this third part appears in the work of Ceder (*14*), along with a procedure to treat also multiple departures (same and more than one departure time in the given timetable).

The minimax *H* algorithm is now applied to the example problem presented in Figure 3. The given and required number of departures for each hour and direction of travel are indicated in Figure 5. Four G_m networks are constructed to derive the minimax headway. This derivation appears in the figure with a dashed line indicating the optimal path on G_m and the labels of the shortest-path algorithm according to Equation 7. A dashed line with an arrowhead indicates the direction of another optimal solution. Also note that t_n between

7:00 and 8:00 becomes t_1 for 8:00–9:00 to preserve the continuity of the analysis. The other parts of Figure 5 are self-explanatory. In all four cases there is no need to proceed to the third part of the minimax H algorithm because all required departures are determined by the modified shortest-path algorithm.

Practical Consideration

The next step, according to the flowchart (Figure 1), is to use the deficit function approach to determine the minimum fleet size required for the new timetable. Before proceeding to that step, however, the new timetable may need adjustment to comply with two operational transit issues.

The first issue is avoiding a skip-stop operation. The new timetable, following the minimax H algorithm, may have a trip with missing passage (departure) times at some feasible timepoints located after the trip's initial departure point and before its arrival point. Such a situation can occur because of the independent treatment of each feasible timepoint. The interpretation of such a missed passage time is that the trip may skip the considered stop. Such a strategy, at the planning stage, certainly does not lead to saving vehicles (assuming that the trip's travel time is not adjusted and remains as in the original timetable), and it has an adverse effect on the passenger level of service. Therefore these missed passage times in the new timetable are inserted back. This act may further reduce the minimax headway at the timepoints at which the missed times were inserted.

The second issue concerns the beginning and end-of-day operational characteristics. Observation of public timetables worldwide reveals that in the early morning and late at night, the short-turn trips are not inserted in an alternating fashion. That is, the first trip to cover the whole route often starts late compared to other initial (short-turn) trips in the day. Similarly, the last trip in the day to cover the whole route starts early in comparison to the other end-of-day trips. Therefore, in the procedures developed, it is optional for the scheduler to decide whether or not the following strategy should be used: in the first and last time periods in the day, the excluded departure times are all extracted from the beginning and end of the times that appear in the complete timetable for that day.

OPTIMAL EXTENSION OF DETERMINED SHORT-TURN TRIPS

In the example problem in Figure 3, after the deletion of departures at timepoints A and B in directions $A \rightarrow C$ and $C \rightarrow A$ (see Figure 5), it is possible to construct the new timetable with the deficit functions. This time, however, all three timepoints (A, B, C) are involved. That is, in the modified timetable, some trips begin at B and some terminate at B in directions $A \rightarrow C$ and $C \rightarrow A$, respectively. Hence point B becomes also an end/start point, and the deficit function description can be applied to it. The new timetable and deficit functions are presented in Figure 6. By using the deficit function approach, it is possible to insert a single DH trip from C to B to arrive before or at 8:35 (the beginning of the $d(B, t)$ maximal interval). This results in a minimum fleet size of $N_{\min} = 9$ vehicles, which is a saving of one vehicle in comparison with the fleet required for the timetable in Figure 3. The timetable in Figure 6 is characterized by the maximum determined short-turn trips for minimizing the fleet size. A method to reduce (minimize) the number of short-turn trips, provided that $N_{\min}$ is maintained, is presented next.

Extensions of Deadhead Trips

Denote the modified timetable with maximum short turns by T'; the route and points by r_i, $i = 1, 2$; and the intermediate short-turn points (belonging to the set R) by U_j, $U_j \in R$, $j = 1, 2, \ldots, V$, where there are V short-turn points. To attain $\overline{N}_{\min}$, the overall schedule to carry out T' might also include DH trips. This overall schedule is designated S. In this section, the deficit function properties are exploited to check whether a DH trip can be interpreted as an extension of a short-turn trip in T'.

By using the deficit function theory, a DH trip can be inserted in a certain time window to reduce the fleet size by one. To simplify this possibility, a DH trip is inserted from one terminal to terminal k so that its arrival time always coincides with the first time that $d(k, t)$ attains its maximum. The following steps attempt to describe the procedure used to convert DH trips in S into service trips used in the original timetable:

1. Select a DH trips in S and call it DH; if there is no such trip in S, *stop*.
2. If the DH trip is from U_j to $r_i = r$ ($i = 1$ or 2, $U_j \in R$), go to Step 3. If the DH trip is from $r_j = r$ to U_j ($i = 1$ or 2, $U_j \in$ R), go to Step 4. If the DH trip is from U_j to U_k (U_j, $U_k \in R$), go to Step 5.
3. Examine an arrival in $d(U_j, t)$ left of the departure time of DH (start with the one closest to that departure time and proceed to the left) to see whether it can be extended to r (by replacing DH). If the considered arrival is associated with trip P_l, the extension can be executed if and only if the following three conditions are met: the arrival time of P_l at U_j is within the hollow that contains the DH departure time, P_l was originally planned to continue toward r (as DH), and the originally planned arrival time of P_l at r is equal or less than the arrival time of DH. If all the three conditions are fulfilled, delete DH from S, update T', $d(U_j, t)$, and $d(r, t)$, and go to Step 1. Otherwise, DH remains in S; go to Step 1.
4. Examine a departure in $d(U_j, t)$ that is right of the arrival time of DH (start with the one closest to that arrival time and proceed to the right) to see whether it can be extended to r (by replacing DH). If the considered departure is associated with trip P_2, the extension can be executed if and only if the following three conditions are met: the departure time of P_2 at U_j is less or equal to the arrival time of DH, P_2 was originally planned to start at r (as DH), and the originally planned departure time of P_2 at r is within the hollow that contains the DH departure time. If all three conditions are fulfilled, delete DH from S, update T', $d(r, t)$, and $d(U_j, t)$, and go to Step 1. Otherwise, DH remains in S; go to Step 1.
5. Set $U_k = r$ and use the procedure in Step 3: if it is terminated successfully (DH is converted to a service trip), execute Adjustment A as follows and go to Step 1. Otherwise, set $U_j = r$ and use the procedure in Step 4. If it is terminated

Direction	A - C			C - A		
Time-point	*A*	*B*	*C*	*C*	*B*	*A*
	7:00	7:15	7:40	7:00	7:20	7:35
	7:10	7:25	7:50	7:15	7:35*	-
	7:25	7:40	8:05	7:20	7:40	7:55
Time-	-	7:50*	8:15	7:25	7:45*	-
	-	7:55*	8:20	7:30	7:50*	-
table	7:45	8:05	8:30	7:40	8:00	8:15
	-	8:10*	8:35	7:50	8:10	8:25
T_1**	8:00	8:20	8:45	8:05	8:30	8:45
	-	8:35*	9:00	8:15	8:40	8:55
	8:25	8:45	9:10	8:20	8:45*	-
	8:40	9:00	9:25	8:27	8:52	9:07

* Departures at *B* (direction *A* - *C*), and arrivals at *B* (direchtions *C* - *A*)

** with *DH* trip from *C* to *B* (8:30 - 8:35)

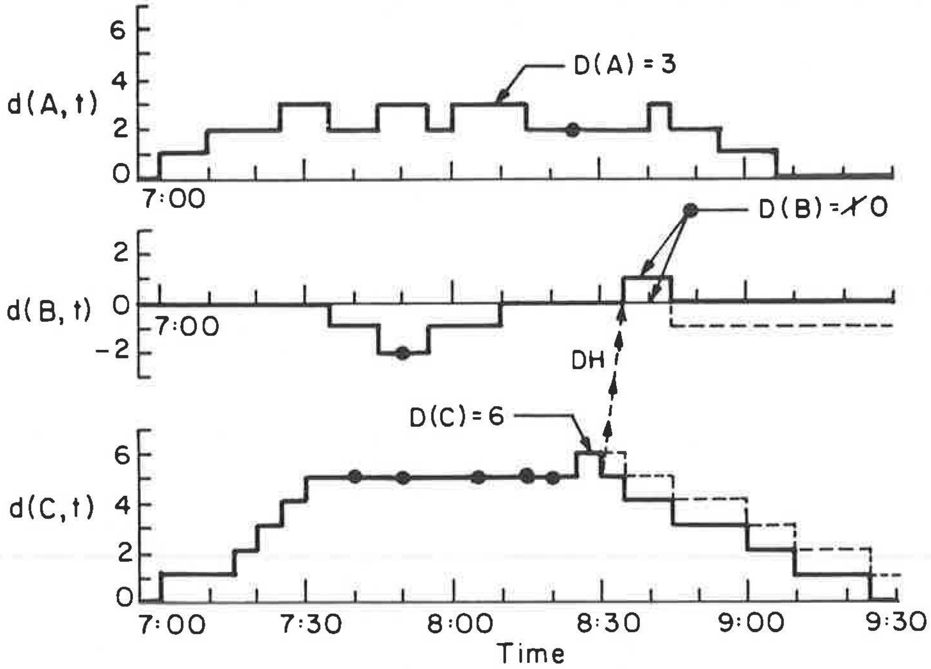


FIGURE 6 New timetable with maximum excluded departure times and associated deficit functions.

successfully, execute Adjustment A and go to Step 1. Otherwise, DH remains in S; go to Step 1. Adjustment A: Delete DH from S; update T', $d(U_j, t)$, and $d(U_k, t)$.

Extensions at Intermediate Short-Turn Points

T'_1 is used to denote updated timetable T', including the extensions of DH trips. This T'_1 is now subjected to further extensions at each $U_j \in R$. An extension of a short-turn trip can be viewed as stretching the trip toward the route end points, r_i $(i = 1, 2)$. An extension does not necessarily mean that the short-turn trip is converted to a full trip along the entire route because it can be only partially extended. That is, an extension can be performed from U_j to U_k (U_j, $U_k \in R$). The three stages at which the extensions at $U \in R$ can be analyzed and executed are as follows: zeroing the maximum deficit function, stretching the maximal interval, and treating the deficit function hollows.

Zeroing the Maximum Deficit Function

On the basis of the deficit function properties, it is possible to prove that while $N_{\min}$ is preserved, the number of extensions in each $U_j \in R$ from U_j to r_i $(i = 1$ or $2)$ is greater than or equal to $D(U_j)$. This rule is based on the observation that in each $U_j \in$ R, exactly $D(U_j)$ departures can be extended to their original departure point without increasing the required fleet size $N_{\min}$. This procedure will eventually lead to

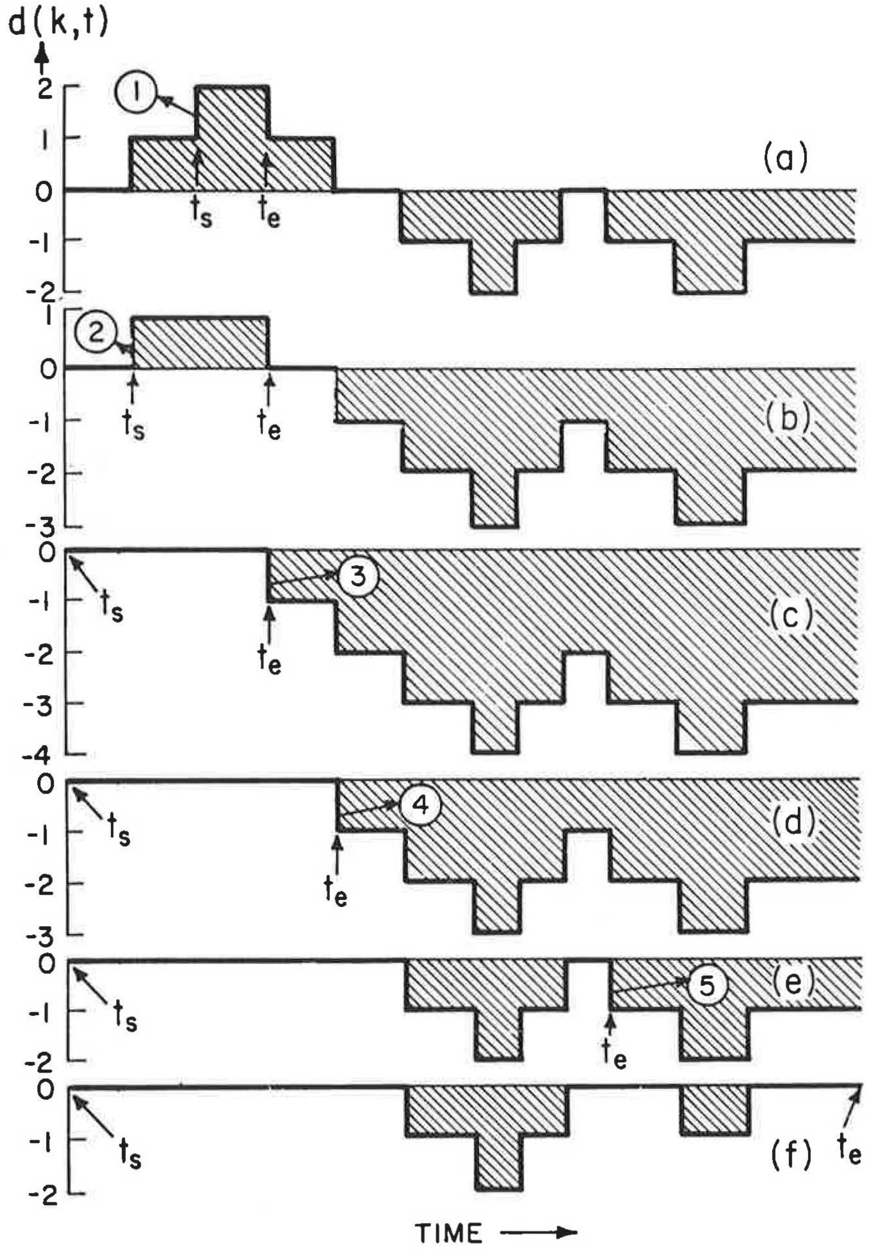


FIGURE 7 Updated deficit functions at an intermediate short-turn point $U_j = k$ after each of the five indicated extensions.

$D(U_j) = 0$ for all $U_j \in R$. These extensions are obtained through the following basic steps, where t_s and t_e denote the beginning and end of the deficit function maximal interval.

1. Initialization: set $R = \bar{R}$.
2. Select an intermediate timepoint $U_j \in \bar{R}$; if $\bar{R} = \emptyset$ (empty), *stop*.
3. Check to see whether $D(U_j) = 0$; is so, delete U_j from $\bar{R}$ and go to Step 2; otherwise, *continue*.
4. Identify a trip (there might be more than one) whose departure time is at t_s of $d(U_j, t)$ and extend this departure to its original time at r_i ($i = 1$ or 2). Update T'_1, $d(U_j, t)$, and $d(r_i, t)$ and go to Step 3.

Figure 7 illustrates an example of five extensions on the deficit function $d(k, t)$. The first two (numbered 1 and 2) induce $D(k)$ to decrease from 2 to 0. Each extension in Figure 7 refers to a different case, and $d(k, t)$ is updated in sequence. The maximal interval of $d(k, t)$ is indicated by its boundaries t_s and t_e.

Stretching the Maximal Interval

After reducing all $D(U_j)$ to zero, it is possible to prove the following rule: while preserving $N_{\min}$, further extensions can be performed from $U_j \in R$ to r_i ($i = 1$ or 2), up to the point at which the maximal interval is stretched over the whole span of the schedule horizon. This rule is based on the observation that certain arrivals can be extended without increasing $D(U_j)$

above 0. The span of the schedule horizon is determined by the earliest departure and latest arrival of the original timetable.

These additional extensions to the route end points are executed using the following steps, where T_2' denotes the updated timetable after the stage described previously (zeroing the function):

1. Initialization: set $R = R'$.
2. Select $U_j \in R$; if $R = \emptyset$, *stop*.
3. Check whether the U_j's maximal interval (from t_s to t_e) coincides with the span of the schedule horizon; if so, delete U_j from R' and go to Step 2. Otherwise, continue.
4. Identify a trip (there might be more than one) such that its arrival is at t_e of $d(U_j, t)$ and extend this arrival to its original time at r_i ($i = 1$ or 2). Update T_2'. $d(U_j, t)$, and $d(r_i, t)$, and go to Step 3.

The above procedure is demonstrated by cases c, d, and e in Figure 7. In each case, t_e is updated, and in case f the procedure stops when the $d(k, t)$s maximal interval coincides with the span of the schedule horizon.

Treating the Deficit Function Hollows

At this third stage, a search is made to determine more extensions at $U_j \in R$ for departures and arrivals in hollows. Each hollow in $d(U_j, t)$ contains the same number of arrivals as it does departures. The procedure developed does not treat hollows, which consist of only one point. In Figure 7, Case f, for example, there are two hollows. The first consists of two arrivals followed by two departures, and the second is a single arrival and departure. The deficit function theory (*8*) permits construction of the following extension search procedure in which T_3' denotes the updated timetable after the stages just discussed:

1. Initialization: set $\bar{R} = \bar{R}'$.
2. Select $U_j \in \bar{R}'$; if $\bar{R}' = \emptyset$, *stop*.
3. Check the next trip (with respect to time) in $d(U_j, t)$. If it is the last departure, go to Step 2. If it is an arrival, go to Step 5. Otherwise, continue.
4. Examine this departure. Extend it to its original time at r_i ($i = 1$ or 2). Execute this extension if $D(r_i)$ is unchanged or if $D(r_i)$ is increased, but if it can be reduced (back) through the Unit Reduction DH Chain (URDHC) procedure (*9*), update T_3' and all the involved deficit functions. Then, if t_e of $d(U_j, t)$ does not coincide with the right boundary of the schedule horizon, go to the extension procedure described in the previous stage (Stretching the Maximal Interval). Otherwise, go to Step 3. If the extension cannot be made, repeat this extension examination toward a different intermediate short-turn point U_k (instead of r_i) each time, selecting the points backward from r_i to U_j.
5. Examine this arrival. Extend it to its original time at r_i ($i = 1$ or 2) and use the URDHC procedure to check whether $D(U_j)$ can remain the same. If so, execute the extension, update T_3' and all the involved deficit functions. Otherwise, repeat this extension examination the same way as in Step 4.

Finally, if a new DH trip is introduced according to this procedure, the procedure for extensions of deadhead trips needs to be repeated.

Extensions on the Example Problem

The minimax H method was applied in Figure 5 to the example problem described in Figure 3. The resultant timetable T_1 (with maximum short-turns) appears in the upper part of Figure 8. The deficit functions of this timetable show that 10 vehicles are required to carry out the timetable without DH trips and that 9 vehicles are required with a single DH trip from $d(C, t)$ to arrive at $d(B, t)$ at 8:35. This is shown explicitly by Figure 6, with $N_{\min} = 9$.

The procedure for extensions of deadhead trips is used to determine whether the DH trip can be converted into a service trip. This examination reveals that the conversion cannot be performed, and hence the DH trip remains in the schedule.

After this first attempt, the procedures described for intermediate short-turn point extensions are applied. Because $D(B) = 0$, the algorithm in the first stage cannot be utilized. Because of the algorithm in the second stage, Extension 1 can be performed (see Figures 8 and 9). Then the algorithm in the third stage c is used. It can be observed that Extension 2 alone affects $D(B)$, increasing it by one at 8:10. The URDHC procedure therefore searches for a DH trip that can arrive at B at 8:10. Such a DH trip is inserted from A while ensuring that $D(A)$ remains 3.

The final step is to check the newly inserted DH trip with the procedure for extension of deadhead trips. This permits Extension 3 to be performed. Consequently, among the eight short-turn trips in timetable T_1 of Figure 8, three were extended to their original schedule, but $N_{\min}$ remains 9. In other words, the procedures developed identify the minimum (crucial) allowed short-turn trips that are required to reduce fleet size. Figure 9 illustrates the updated deficit functions after the three extensions. It can be observed that no more extensions can be made. In addition, timetable T_2 in Figure 9 is the final recommended timetable.

VEHICLE BLOCKS

In this section, a procedure is described to assign each of the $N_{\min}$ vehicles to a group of trips in the final schedule. A single group of trips, called a block, exhibits a sequence of service and deadhead trips for an individual vehicle.

The task of scheduling vehicles to chains of trips can be carried out by the first in–first out (FIFO) rule or by a chain extraction procedure described by Gertsbach and Gurevich (*6*). Here, the FIFO rule is used to construct the $N_{\min}$ vehicle blocks. This rule can be stated as follows: Arrange the list of all trips in the final schedule (the trips in the final timetable and the required DH trips for achieving $N_{\min}$) by their departure time order (disregard locations and direction of travel). Select the first trip on the list and join it to its first feasible successor, which is the first trip down the list that has the same departure location as the arrival location of the last trip selected and has a departure time greater than or equal to the arrival time of the last trip selected. If no such trip is found, then remove all the selected trips from the list, maintaining their order, and assign them to a single block. This

Max. load points

Direction	A - C			C - A		
Time-point	*A*	*B*	*C*	*C*	*B*	*A*
Time-table *T*1 with maximum short-turns**	7:00	7:15	7:40	7:00	7:20	7:35
	7:10	7:25	7:50	7:15	7:35*	-
	7:25	7:40	8:05	7:20	7:40	7:55
	-	7:50*	8:15	7:25	7:45*	-
	-	7:55*	8:20	7:30	7:50*	-
	7:45	8:05	8:30	7:40	8:00	8:15
	-	8:10*	8:35	7:50	8:10	8:25
	8:00	8:20	8:45	8:05	8:30	8:45
	-	8:35*	9:00	8:15	8:40	8:55
	8:25	8:45	9:10	8:20	8:45*	-
	8:40	9:00	9:25	8:27	8:52	9:07

* Departures at *B* (direction *A* - *C*) and arrivals at *B* (direction *C* - *A*)
** with a *DH* trip from *C* to *B* (8:30 - 8:35)

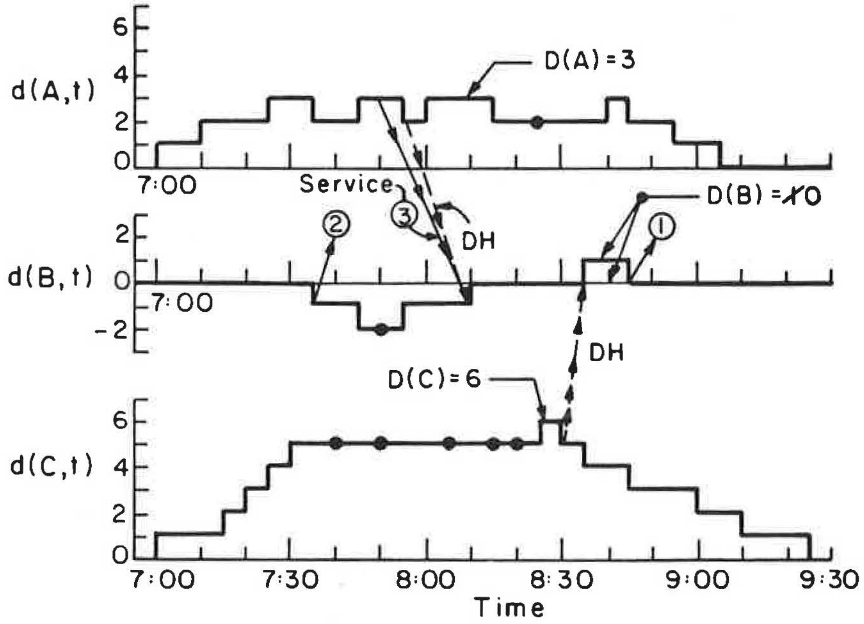


FIGURE 8 Modified timetable and deficit functions following the minimax *H* algorithm, with indication of three short-turn trip extensions.

forms the first vehicle block. Repeat the process with the reduced list to create the next vehicle block. Stop when the list is empty.

This FIFO rule is applied to the example problem to construct the nine blocks given in Tables 1 and 2. The basic 23-trip list for this method is presented in the upper part of Table 1, where no DH trip is required to obtain $\bar{N}_{\min} = 9$.

In the software developed in this work, each block is also accompanied by certain performance measures. These computer-generated measures, along with the generated final timetable, are required for the next scheduler's task (assigning drivers to the blocks). Each block has six performance measures:

- Total service time (minutes),
- Total deadheading time (minutes),
- Total idle time (minutes),
- Total service kilometers (or miles),
- Total deadhead kilometers, and
- Total block time (minutes).

Idle time is the vehicle's waiting time in the same location between two adjacent trips in the block. In addition, the software provides the sum, over all blocks, of each measure.

CONCLUSIONS AND FUTURE WORK

The final product of this work is a set of programs that execute all the components and tasks described in Figure 1. The outcome of this work can generally be presented in light of the five objectives set forth in the first section. The procedures

Direction	A - C			C - A		
Time-point	*A*	*B*	*C*	*C*	*B*	*A*
Time-	7:00	7:15	7:40	7:00	7:20	7:35
table	7:10	7:25	7:50	7:15	7:35	(7:50)
T_2*	7:25	7:40	8:05	7:20	7:40	7:55
with	-	7:50	8:15	7:25	7:45	-
minimum	-	7:55	8:20	7:30	7:50	-
short-	7:45	8:05	8:30	7:40	8:00	8:15
turns	(7:50)	8:10	8:35	7:50	8:10	8:25
but same	8:00	8:20	8:45	8:05	8:30	8:45
number	-	8:35	9:00	8:15	8:40	8:55
of	8:25	8:45	9:10	8:20	8:45	(9:00)
vehicles	8:40	9:00	9:25	8:27	8:52	9:07

(9:00) extension①, (7:50) ext.②- arrival, (7:50) ext.③- departure

* with a *DH* trip from *C* to *B* (8:30 - 8:35)

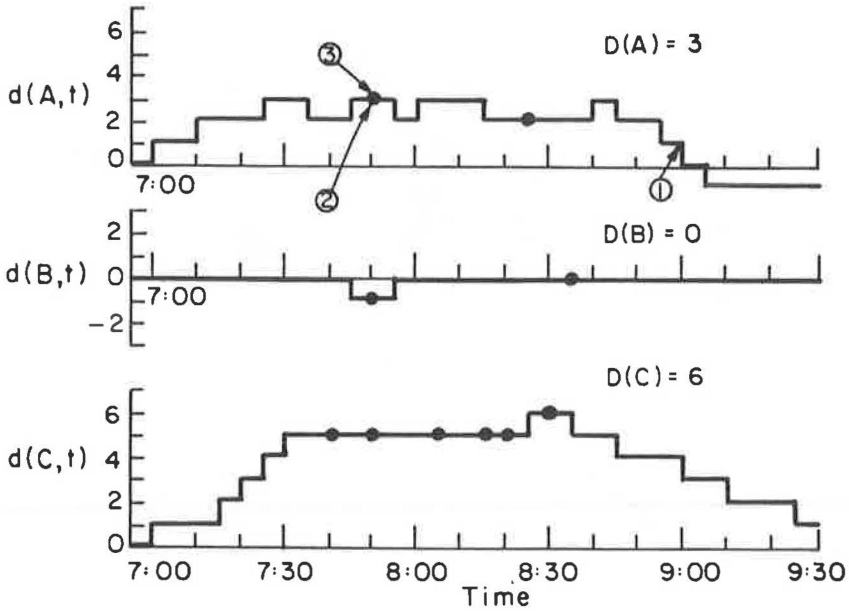


FIGURE 9 Optimal timetable of the example problem, with updated deficit functions and the three extensions.

developed provide the transit scheduler with a set of feasible short-turn points extracted from the description of passenger load profile in each time period of the day. They also provide the approach and methods for determining the minimum fleet size required to carry out a given schedule. These procedures fulfill the first and second objectives.

The third objective of this study is to reduce the number of departures at each short-turn point to that required from a passenger load standpoint while attempting to minimize the adverse effects of the reduction on the passenger level of service. This objective is fulfilled by adopting the minimax headway criterion, or in other words, by minimization.of the maximum passenger wait time. The minimax H algorithm described in this paper provides the mathematical tool to handle this criterion. Moreover, the procedures described thereafter allow for an additional improvement of the passenger level of service while preserving the minimum fleet size obtained through the elimination of some departure times. These procedures fulfill the fourth objective of this study.

The need to construct vehicle blocks (schedules) with short turns for the final timetable is expressed in the last objective of this work. The FIFO rule presented in the last section ensures that exactly $\overline{N}_{\min}$ blocks are created, where $\overline{N}_{\min}$ is the optimal (minimum) fleet size required to provide adequate transit service.

Future work should be concentrated along the following lines. The methods should be extended to handle origin-destination data whenever it is available [part of this work is described elsewhere (*13*)]. More than two end route points should be accommodated. A transit route may consist of branches, and the procedures developed can easily be extended to consider such cases. Finally, the procedures should be mod-

TABLE 1 TRIPS BY DEPARTURE TIME ORDER

Trip No.	Departure Time	Departure Location	Arrival Time	Arrival Location
1	7:00	*A*	7:40	*C*
2	7:00	*C*	7:35	*A*
3	7:10	*A*	7:50	*C*
4	7:15	*C*	7:50	*A*
5	7:20	*C*	7:55	*A*
6	7:25	*A*	8:05	*C*
7	7:25	*C*	7:45	*B*
8	7:30	*C*	7:50	*B*
9	7:40	*C*	8:15	*A*
10	7:45	*A*	8:30	*C*
11	7:50	*C*	8:25	*A*
12	7:50	*B*	8:15	*C*
13	7:50	*A*	8:35	*C*
14	7:55	*B*	8:20	*C*
15	8:00	*A*	8:45	*C*
16	8:05	*C*	8:45	*A*
17	8:15	*C*	8:55	*A*
18	8:20	*C*	9:00	*A*
19	8:25	*C*	9:05	*A*
20	8:25	*A*	9:10	*C*
21[a]	8:30	*C*	8:35	*B*
22	8:35	*B*	9:00	*C*
23	8:40	*A*	9:25	*C*

[a] Deadhead.

TABLE 2 DESCRIPTION OF BLOCKS DERIVED BY THE FIFO METHOD

Block (Vehicle) No.	Departure Location	Departure Time	Arrival Location	Arrival Time	Trip No.
1	*A*	7:00	*C*	8:40	1
	C	7:40	*A*	8:15	9
	A	8:25	*C*	9:10	20
2	*C*	7:00	*A*	7:35	2
	A	7:45	*C*	8:30	10
	C[a]	8:30	*B*	8:35	21
	B	8:35	*C*	9:00	22
3	*A*	7:10	*C*	7:50	3
	C	7:50	*A*	8:25	11
	A	8:40	*C*	9:25	23
4	*C*	7:15	*A*	7:50	4
	A	7:50	*C*	8:35	13
5	*C*	7:20	*A*	7:55	5
	A	8:00	*C*	8:45	15
6	*A*	7:25	*C*	8:05	6
	C	8:05	*A*	8:45	16
7	*C*	7:25	*B*	7:45	7
	B	7:50	*C*	8:15	12
	C	8:15	*A*	8:55	17
8	*C*	7:30	*B*	7:50	8
	B	7:55	*C*	8:20	14
	C	8:20	*A*	9:00	18
9	*C*	8:25	*A*	9:05	19

[a] Deadhead.

ified to handle a network of interlinking routes, in which a vehicle can transverse from one route to another in its block. When interlinking routes are allowed, the minimum fleet size can be reduced further (in comparison with the operation of independent routes).

ACKNOWLEDGMENT

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New York City's Unfranchised Buses: Case Study in Deregulation

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The unfranchised buses operating in New York City are certified by the Interstate Commerce Commission and New York State DOT. They are not subject to the city's extensive review process, which attempts to balance traffic, economics, and community impacts. These buses, in their operations as commuter expresses, Atlantic City specials, charters, and tour buses, provide a valuable service to their passengers; however, they also add to congestion throughout Manhattan. Unfranchised buses account for about a fifth of all buses entering Manhattan streets south of 63rd Street. Their growth is a direct result of the federal and state deregulation of intercity bus operations in the early 1980s. In this paper, short-term actions are suggested to improve the operation of unfranchised buses within the existing legal framework. For the long term, the authors suggest legislative changes that exempt the city from Interstate Commerce Commission control over intrastate bus services operated by interstate carriers. They also suggest that further legislative changes in other large metropolitan areas may redress the balance between federal and local control of intrastate bus service.

The effects of transportation deregulation over the past decade have become increasingly apparent, including greater profitability of railroads, proliferation of motor freight carriers, expansion of airlines with selective price cuts (followed by contraction), and a decline in intercity bus services. Federal and state deregulation have produced somewhat different effects in the New York Metropolitan Area. Over the past decade, deregulation has brought about a dramatic growth in the number of "unfranchised buses," which are certified to operate by the New York State Department of Transportation (NYSDOT) or the Interstate Commerce Commission (ICC). These buses account for about one-fifth of all buses operating on Manhattan streets south of 63rd Street. About 74 percent of the new bus routes authorized between 1984 and 1986 were certified by the ICC, compared with 3 percent a decade earlier (Figure 1).

The unfranchised buses operate as regular or contract services. They include

- Legitimate NYSDOT- and ICC-certified commuter buses,
- "Bogus" ICC commuter buses (buses with ICC permits that serve only New York City or New York State),
- Tour and charter buses, and
- Atlantic City buses.

The growth of these services stems from

- The increased vitality of Manhattan as a tourist destination;
- The growing commuter populations in Staten Island and New Jersey, which have created new markets; and

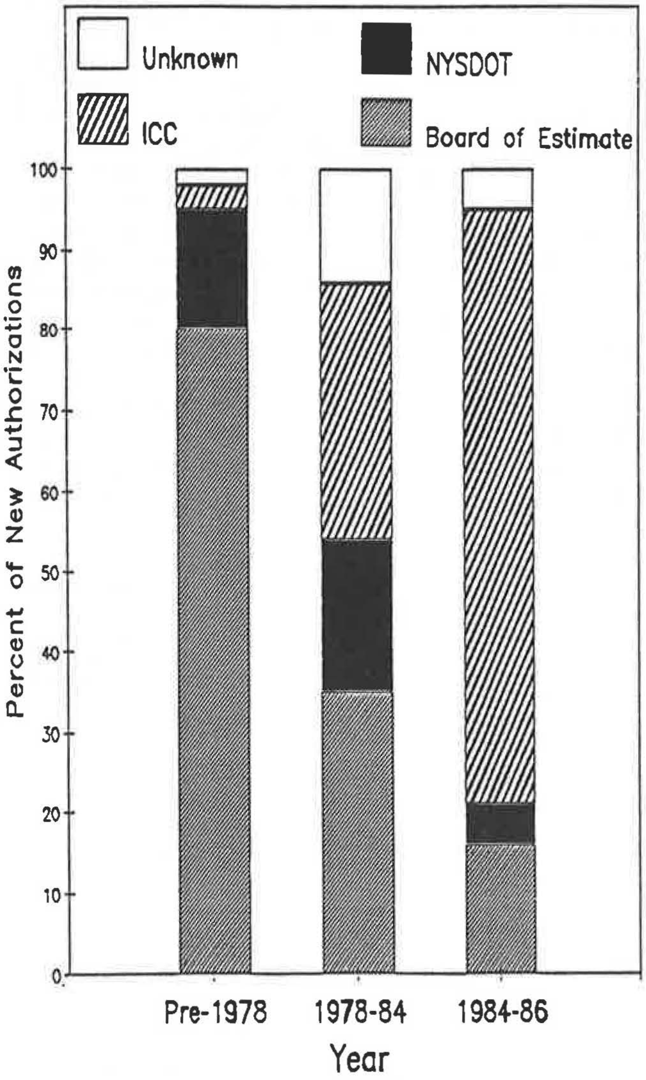

FIGURE 1 New express bus route authorizations: percentage of total by certifying agency (data from 1984 and 1986 NYCDOT surveys).

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- The deregulation of intercity bus operations and the easing of entry requirements by the federal Bus Regulatory Reform Act of 1982.

ISSUES AND APPROACH

The unfranchised commuter buses are privately operated, and they usually run without subsidies from public agencies. They provide a desirable service to users. From the federal perspective, they reflect privatization of urban transit.

They are of major concern to New York City, however, because the city government has little say regarding when, where, and how the buses operate. These vehicles increase traffic congestion on already overcrowded streets in Midtown and Lower Manhattan. They conflict with other vehicles at bus stops and in on-street layover areas. They add to environmental pollution at the very time that the city is trying to improve air quality. Finally, along with vans and certain unfranchised buses, they sometimes "poach on" and undermine subsidized commuter rail and subway lines.

Accordingly, in 1986, the New York City Department of Transportation (NYCDOT) began a cooperative research effort with Polytechnic University (Brooklyn, New York) to assess problems and to identify opportunities. The study objectives were to analyze the operational and institutional aspects of the "unfranchised bus problem" within the broader context of the city's need for coordinated transport services (*1*).

The study was designed to place the conflicting needs in clearer perspective. Existing reports dealing with bus operations and terminal plans were reviewed. Detailed surveys were made of the number and types of buses entering the Manhattan business district and of bus parking practices in tourist areas. Field reconnaissance investigations identified problems and opportunities, and community boards and bus operators were interviewed. The legal bases for franchising buses were analyzed. Meetings were held with public agencies and the bus operators.

This paper summarizes the key findings and recommendations. The problems that the authors describe could arise in other large, growing bistate metropolitan areas.

DIMENSIONS AND ATTITUDES

Each weekday, about 2,700 buses enter the Manhattan central business district south of 63rd Street from 7 A.M. to 12 noon. Of these, about 29 percent are New York City Transit Authority (NYCTA) local buses, 13 percent NYCTA express buses, 40 percent franchised express buses, and 18 percent unfranchised buses. These figures, presented in Table 1, exclude the buses going to and from the Port of New York and New Jersey Bus Terminal (PABT).

Screen Line Bus Entrants

The number of buses entering Manhattan streets across various screen lines between 7 A.M. and 12 noon is given in Figure 2. The proportions of unfranchised buses are as follows:

Location	*Percentage*
63rd Street	7
44th Street	10
Canal Street	20
East River	7
Hudson River	83

(excluding PABT)

Figure 2 demonstrates how the numbers and proportions of unfranchised bus flows build up from the north to the south. The heaviest concentrations of unfranchised buses are found in Lower Manhattan.

Express Bus Operators

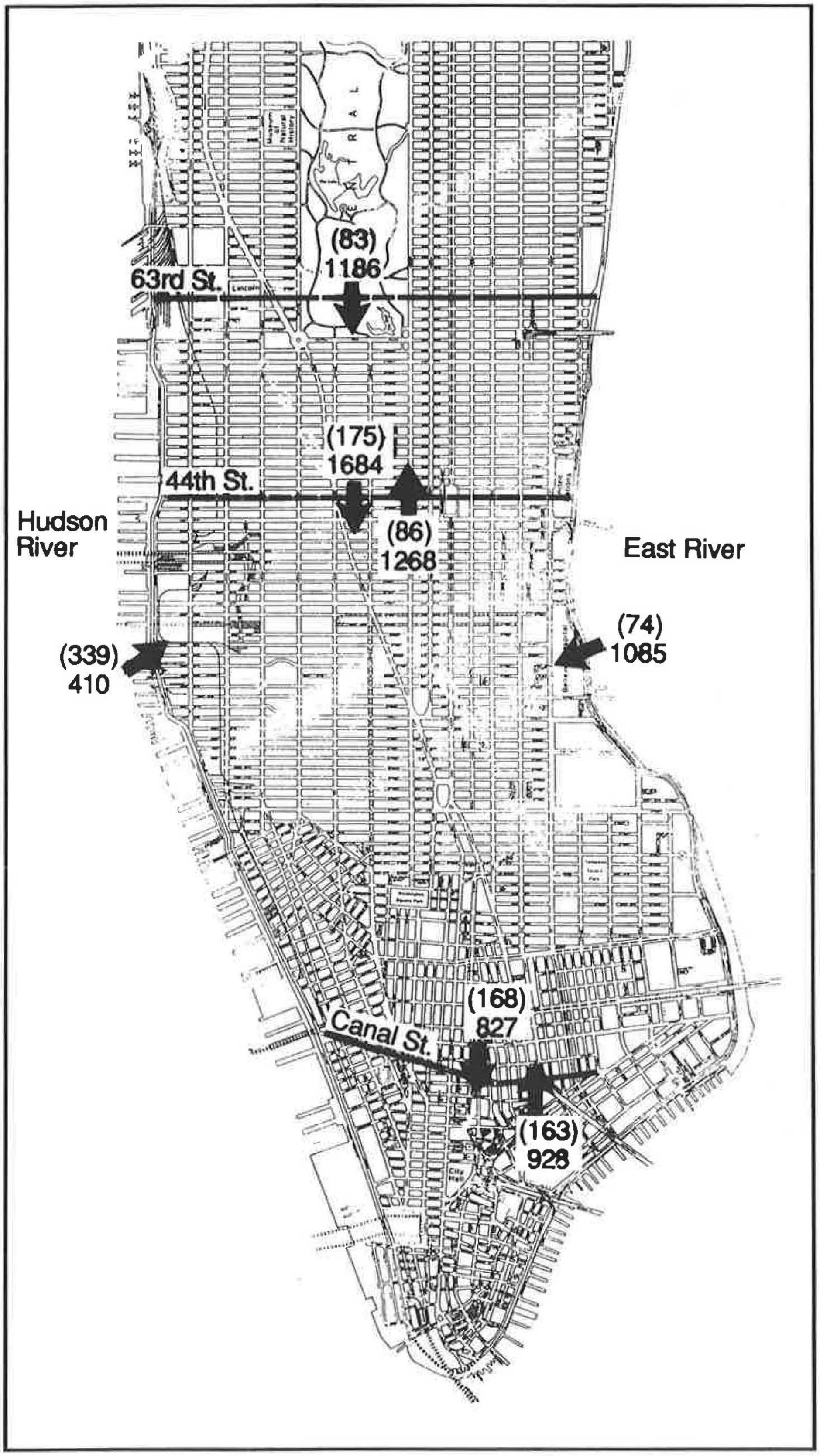
Most of the unfranchised buses operating in Manhattan are certified by the ICC, but ICC records do not include size, service, and financial characteristics. To fill this void, 15 unfranchised commuter operators were asked about their fleet characteristics and operating practices. The key findings are presented in Table 2 and below. Collectively, 13 companies operated some 566 buses in commuter service to and from Manhattan in 1986.

TABLE 1 SUMMARY OF BUSES ENTERING MANHATTAN BELOW 63RD STREET, 7 A.M.-12 NOON ON A WEEKDAY, FALL 1986

	63rd St.		Hudson River		East River		Total		
Type of Service	No.	%	No.	%	No.	%	No.	%	Percent Unfranchised
NYCTA local	648	54.6	0	0	128	11.8	776	28.9	NA
NYCTA express	52	4.4	0	0	299	27.5	351	13.1	NA
Subtotal	700	59.0	0	0	427	39.3	1127	42.0	NA
Franchised	403	34.0	71	17.3	584	53.9	1058	39.5	NA
Unfranchised									
NYSDOT commuter	7	0.6	30	7.3	24	2.2	61	2.3	12.3
NYSDOT local	12	1.0	23	5.6	11	1.0	46	1.7	9.3
ICC commuter	29	2.4	233	56.9	31	2.9	293	10.9	59.1
ICC charter	35	3.0	53	12.9	8	0.7	96	3.6	19.3
Subtotal	83	41.0	339	82.7	74	60.7	496	18.5	100.0
Total	1186	100.0	410[a]	100.0	1085	100.0	2681	100.0	
Percentage	44.2		15.3		40.5				

NOTE: Excludes buses entering Port Authority Bus Terminal. NA = not applicable. Source: NYCDOT survey, October 1986.

[a] Includes local buses operated by franchised carriers.



Note:

Figures include deadheads and local buses

(22) = Unfranchised buses
111 total

FIGURE 2 Buses on Manhattan streets, 7 A.M. to 12 noon on a weekday, fall 1986.

TABLE 2 SUMMARY OF UNFRANCHISED EXPRESS BUS SURVEY, 1987

Carrier	Size Fleet	Avg. Age (yr)	Operating Authority	Origin	Point of Entry	Buses Entering Manhattan, A.M. Peak	Estimated Daily Passengers Carried	Would Use Garage or Lot for . . .		
								Short-Term Layover	All-Day Parking	Passenger Terminal
Academy	116	4	ICC/NYSDOT	Staten Is./ New Jersey	Holland Tunnel	90	3,500	Yes	Yes	?
Boulevard Transit	25	15+	ICC	Staten Is./ New Jersey	Holland Tunnel	10	150	Yes	No need	Yes
Erin Tours	20	5	ICC/NYSDOT	Brooklyn	Brooklyn-Battery Tunnel	15	485	No	No	Problem: passengers' long walk
Glen Ridge	9	9	NYSDOT/ICC	Long Is.	Midtown Tunnel, Williamsburg Bridge	7	315	No	No	No
Montauk Bus Co.	35	4	ICC	Montauk, Long Is.	Midtown Tunnel	9		Yes	–	Yes
Murrell	8	3	ICC/NYSDOT	Staten Is.	Lincoln Tunnel	4		–	–	–
Pocono Mountain Trails	10	6	ICC/NYSDOT, PA/PUC	New Jersey	Holland Tunnel	2	80	Yes	Yes	Yes, if reasonable
Prospect Slope Coach Co.	NA	NA	[a]	Brooklyn	NA	1–2	40	–	–	–
South River Bus Co.	17	5	ICC/NYSDOT	New Jersey	Lincoln and Holland Tunnels	4		–	Yes	Yes
Service Bus Co.	12	3	NYSDOT	Westchester	Deegan Expwy.	2		Yes	Yes	Yes (great)
Scott Tours	9	12	ICC/NYSDOT	New Jersey	Holland Tunnel	3		Good idea	–	Yes
Suburban Transit	275	NA	ICC/NJDOT	New Jersey	Holland Tunnel	14	500	Possibly	Possibly	Possibly
Vanguard Tours	20	6	NYSDOT, WESTCH DOT	Armonk, Ossining, N.Y.	Deegan Expwy.	5		Yes	Yes	NA
Totals	566					167		Yes (8)	Yes (5)	Yes (6)

NOTE: Source: NYCDOT Survey, April 1987.

[a] Application in process.

There is a wide diversity in the size and age of fleet, quality of service, method of operation, and capability of management. The unfranchised bus services involve many small carriers. The median fleet size was about 20 buses, with a range of 8 to 275 buses. Only two carriers had fleets of more than 35 buses.

Ten companies operated under ICC authorization (many also were registered with the New Jersey Department of Transportation—NJDOT). Two operated under NYSDOT authorization, and one had its application to operate pending.

Four companies ran between New Jersey and Manhattan, while another two provided service to both Staten Island and New Jersey. Two companies provided service between Manhattan and Brooklyn. One of these had an ICC/NYSDOT/NJDOT permit, and the other had an application pending. Two carriers provided service between Long Island and Manhattan under an ICC permit. Two carriers operated to and from Westchester, Duchess, and Putnam counties with NYSDOT permits.

About half of the carriers (six) entered Manhattan via the Holland Tunnel, while the others used the Midtown Tunnel (two), Lincoln Tunnel (one), Brooklyn Battery Tunnel (one), and Major Deegan Expressway (two). Collectively, some 167 buses entered Manhattan via these approaches during the 7–10 A.M. peak period. The number of reported passengers ranged from fewer than 150 (Boulevard, Pocono Mt. Trails, Prospect Slope Coach) to more than 3,500 (Academy).

The companies were asked about their use of garages or parking lots for layovers or parking or as passenger terminals. Eight companies (out of ten responses) used such a facility for short-term layover, five companies (out of nine responses) used it for all-day parking, and six companies (out of ten responses) used it for a passenger terminal.

The problems reported by the bus operators are outlined below:

- *Comments*
  - Too much traffic.
  - Traffic delays.
  - Tunnel is slow.
  - Tunnel and city streets near gridlock.
  - Bus-van-truck conflicts.
  - Lack of regard for traffic regulations on Church Street.
  - Lack of curb space at some stops.
  - Another company blocks stops around Javits Center.
  - No legal layover or staging areas.
  - Desperate for parking areas.
  - Severely harassed by transit authority plainclothesmen.
  - Can't load bus in 5 minutes.
  - Idling low poses a problem.
  - "Little guys take beating."

- *Suggestions for Improvement*
  - Need another tube in each tunnel.
  - Designate bus-only streets.
  - Need eastbound left turn-around at Battery Place and Trinity.
  - Would like authorization to use tunnel bus lane in morning.
  - Need bus boarding areas or terminal.
  - Need 5–10-min staging facilities.
  - Need layover areas with facilities for rest or eating.

Principal concerns included traffic congestion, conflicts between buses or with vans, the lack of parking, difficulties in meeting regulations, and delays and difficulties in receiving a franchise. This last concern is significant because it also was mentioned at meetings with bus operators as one reason why these companies obtain ICC permits rather than New York City franchises.

Suggestions for improvement covered a wide range of possibilities. They ranged from more trans-water capacity for buses (i.e., "another tube in each tunnel") to the desirability of additional staging and layover areas. Four suggestions called for traffic improvements, and three for parking layover or loading improvements.

Tour and Charter Bus Operations

Tour and charter buses congregate at and near the major tourist attractions. These attractions include the Art and Natural History museums, Lincoln Center, Rockefeller Center, Times Square theater district, United Nations, Empire State Building, Chinatown, World Trade Center, South Street Seaport, and the Statue of Liberty Ferry.

Bus activity varies by day of the week and by time of year. Bus service to most tourist attractions peaks during summer months. The principal exception is Rockefeller Center, where activity and bus movements peak between Thanksgiving and Christmas. Theater bus traffic is heaviest for Wednesday and Saturday matinees. The New York City Convention and Visitors Bureau estimated that an average day has about 65 buses, excluding buses with destinations at the theater district. Actual field observations, taken in April 1987, suggest a greater number of buses.

Results of interviews with tour and charter bus operators are summarized in Table 3 and as follows:

- The Times Square Theater District was the most frequently visited attraction, both as a first choice and overall. Next in importance was the Statue of Liberty, followed by the Museum of Natural History.
- Most tour buses parked on street. The Greyhound garage (next in importance) was used for overnight parking. Several

TABLE 3 SUMMARY OF TOUR AND CHARTER BUS SURVEYS AT MAJOR TOURIST ATTRACTIONS

	Ranking			
Attraction	1	2	3	Total
Theater District	7	2	2	11
Statue of Liberty	3	1	3	7
Museum of National History	1	2		3
South Street Seaport	2	2	1	5
Radio City	2	1		3
South Street/Statue of Liberty		1	1	2
United Nations/Statue of Liberty	1			1
Yankee Stadium		1		1
Technical visits		1		1
South Street/World Trade Center	1			1
Total City Tour	4	—	–	4
Total	21	11	7	39

NOTE: Source: NYCDOT survey of 12 tour/charter services.

buses also parked overnight in New Jersey. The museum, Circle Line, and Day Line lots were among the places used for bus layover:

Layover Location	*Responses*
On street	13
Greyhound lot	8
Circle Line lot	2
New Jersey	4
Museum lot	1
Short Line facility	1
Day Line lot	1
	30

- Problems cited included inadequate on-street layover space, driver harassment and ticketing at drop-off points, inadequate passenger loading times, and vandalism at the Greyhound garage:

Remarks

- Vandalism at Greyhound Garage (two).
- Drivers are always ticketed (two).
- Drivers harmed at drop-off points.
- Loading time too short at South Ferry.

Desired improvements

- Need specific places to park (four).
- Desire safe places to park (two).
- Would pay fee for safe parking place (one).
- Eliminate cars (in bus loading areas).
- Park buses in city-owned lot.
- Need better coordination between NYC Convention and Visitors' Bureau and NYCDOT.

As can be observed, suggested improvements centered on providing specific places to park, including the willingness to pay a fee. Respondents also indicated the need for better coordination within NYCDOT and other agencies to ensure that current regulations are being enforced fairly and that buses parking in designated areas are not ticketed.

Table 4 presents data on when and where charter and tour buses parked at the major tourist attractions. Short-term parking (usually less than 30 min) predominated at tourist sites (e.g., Metropolitan Museum of Art, Rockefeller Center). Long-term parking predominated at bus layover areas (e.g., Lincoln Center, 41st Street, Canal Street).

Attitudes and Perspectives

City officials, community boards, and bus operators have differing views on the role, scope, and value of unfranchised bus services.

Community Boards

Table 5 indicates how various community boards perceive unfranchised buses. Boards generally found vans or local bus service (routes and schedules) to be a greater problem. The two community boards in the Times Square area who represent residents in the theater district expressed concerns about bus layovers and loading practices. They also were concerned about van and limousine operations.

Several boards cited problems with the Atlantic City charter buses that operate to and from southern Brooklyn. Buses double park in the moving travel lanes when they pick up and discharge passengers from travel agencies located in commercial areas (e.g., Bath Avenue, 14th Avenue, 3rd Avenue, and 86th Street).

TABLE 4 SUMMARY OF PARKING CHARACTERISTICS AT MAJOR TOURIST ATTRACTIONS, 1987

Location	Date	Number of Parkers	Maximum Accumulation Time	Maximum Accumulation No.	<0.5 hr (%)	0.5 hr < < 1 hr. (%)	1 hr < (%)
Metropolitan Museum of Art (Fifth Ave. btwn. 80 and 85 sts.)	Sat. April 25	33	11:00–11:30	1	88	9	3
	Thurs. April 30	27	3:30–4:00	2	93	7	0
Museum of Natural History environs (Central Park West btwn. 76–82 and 77 and 81 sts.)	Sat. April 25	20	3:00–3:30	3	75	15	10
	Thurs. April 30	36	11:30–12:00	17	44	14	42
Lincoln Center (W. 62nd St. btwn. Columbus and Amsterdam aves.)	Sat. April 25	56	2:00–2:30	22	5	20	75
	Thurs. April 30	58	10:00–10:30	26	26	19	55
Rockefeller Center area (47–51 sts. btwn. 5th and 6th aves., 6th ave., 47–51 sts.)	Wed. April 15	6	4:00–4:30	1	100	0	0
	Wed. April 22	26	4:30–5:00	1	92	8	0
Theater District area (44–49 sts., both sides; Ninth Ave. to Broadway)	Wed. April 15	43	4:30–5:00	5	69	19	12
	Wed. April 22	52	4:00–4:30	16	38	33	29
West 41st St. (11th to 12th aves.)	Wed. April 15	57	2:30–3:00	33	19	10	71
	Wed. April 22	57	1:00–1:30	26	14	16	70
West St. (Canal St. to Battery Pl.)	Thurs. April 9	141	11:00–11:30	41	23	21	56
	Thurs. April 16	129	11:00–11:30	43	24	13	63
Battery Pl. (West St. to Broadway)	Thurs. April 9	85	4:00–4:30	12	64	26	10
	Thurs. April 16	132	12:00–12:30	8	77	15	8

TABLE 5 SUMMARY OF COMMUNITY BOARD RESPONSES, UNFRANCHISED BUS STUDY

Board No.	Areas	Problems	Comments/Solutions
Brooklyn 9	Crown Heights, Wingate	Tour bus congestion on Eastern Parkway, 5 A.M.–10 P.M. School buses block driveways and double park on Kingston Ave. from Carroll to President sts.	Stricter enforcement of curb parking regulation
10	Bay Ridge, Ft. Hamilton, Dyker Heights	Atlantic City charters double park and idle motors, 9–10 A.M., 9 P.M., 86th St. at 5th Ave., 92nd St. and Dalgren Pl., 3rd Ave. Express buses along 14th Ave.	Investigate possible illegal use; revoke permits
11	Bensonhurst, Bath Beach, Gravesend	Atlantic City buses (travel agency, Bath St.) Vans in express bus stops	Make buses use truck routes
18	Canarsie, Flatlands, Mill Basin	Vans making pickups and dropoffs in express bus stops	Prohibit vans and private buses from using express bus stops
Queens 5	Glendale, Maspeth, Ridgewood	Glenridge Coach cited for violations	
–	Richmond Hill Block Association	TA49 too frequent, TA56 too infrequent	Adjust headways
14	Rockaway Park	Vans pick up and discharge passengers in bus stops	License vans
Manhattan 2	Greenwich Village, Soho, Little Italy	Tour buses use illegal streets, park illegally, and leave motors running	Prohibit buses running
4	Clinton, Chelsea	Buses traverse local streets: 9th Ave., 38–39th St.; W. 19th St.; W. 52nd, 8–9th aves.; W. 43rd, 10–11th aves.; W. 46th, 8–9th aves.	
7	Hudson River to Central Park West, 59–110th sts.	Atlantic City buses leave from Broadway, 8–10 A.M.	
6	Murray Hill, Turtle Bay, Gramercy (14–59th sts., Lexington Ave.–river)	Too many express buses, vans, unlicensed taxis	
5	Times Square area (to Hudson River)	"Gigantic" buses in theater district wait on street when shows let out. Buses take routes with many turns. Buses stop on left side of street. Grey Lines take excessive time to load on 53rd Street. Limousines cluster around theater district; enforcement is needed. Vans are all over the place. Commuter vans with ICC permits are a problem.	

NOTE: Source: NYCDOT survey, April 1987.

Bus Operators

The unfranchised bus operators had a somewhat differing array of problems. These included the long delays in the unfranchising process, which are not fully recognized by the city, and the difficulty in obtaining temporary permits. Also cited were the need for more equitable enforcement practices, the need for more layover space in Manhattan (use of unused docking areas along the Hudson River was suggested), and better enforcement of van operations.

City

NYCDOT policy attempts to balance the service provided by specific commuter bus routes or carriers against the negative effects that they have on congestion, pollution, neighborhood disruption, and rail and other subsidized transit. NYCDOT means to apply the same criteria to all carriers; however, the degree of control it can exercise over ICC and NYSDOT carriers is limited. This lack of control—especially with regard to routes, stops, and layover areas—remains an important issue.

The city considers tour and charter buses to be important because they help support the city's tourism industry. Accordingly, it is working with these operators to provide suitable storage and layover space.

Observed Problems

The unfranchised buses vary widely in type and quality of service and in their impacts on New York City streets. The commuter buses compete for valuable street space during peak periods and have added to Manhattan street congestion. They mainly use the Lincoln Tunnel to reach Midtown and the Holland Tunnel to reach Lower Manhattan, where street space is especially limited.

The charter and tour buses pose problems in key activity centers, where they receive or discharge passengers or lay over. The observed problems, presented in Figure 3, are as follows:

- There is no place for buses to lay over and park at the Metropolitan Museum and at Rockefeller Center. Consequently, buses must discharge their passengers and proceed across town to layover areas on the far West Side.
- The number of bus parking and lay over spaces is not adequate to meet demands at the American Museum of Natural History, Lincoln Center (62nd Street), and the Times Square theater district.
- Signage of several bus layover areas is inadequate. "Bus Layover Zone" signs are missing from the West 59th Street and West 54th Street layover zones. Signs are missing from the south side of West 41st Street between 11th and 12th avenues, where buses now park. Signs at Battery Place and in the Theatre District do not clearly specify the allowable time limits.
- Charter and tour buses contribute to street congestion in Times Square and along Eighth Avenue and Broadway. Buses block moving traffic at several locations. Charter buses park (or double park) on Broadway between 47th and 45th Streets immediately before theater matinee performances finish, thereby limiting southbound Broadway traffic to one or two lanes. The same condition occurs along Eighth Avenue between 44th and 45th Streets, where charter buses double park. Traffic on Eighth Avenue has one less moving lane available, and it queues during peak traffic periods.
- Buses load passengers from "street" side of 44th and 46th Streets after theater matinees discharge. This is an undesirable practice for several reasons. First, people must board buses from the center of the street, where they are not protected from moving traffic. Second, passenger boarding activity blocks moving traffic.
- Police and warrant officers park their cars in the designated tour bus loading area along Park Row between Pearl Street and St. James Place. Because parking is permitted on the opposite side of Park Row, adjacent to the Chatham Green Houses, there is no place along the curb for buses to receive or discharge passengers or lay over.
- Bus parking areas that serve the Times Square theater district and the South Street Seaport are too remote from these areas. The remoteness further results in buses waiting closer by, albeit illegally.

LEGAL CONTEXT

Bus lines are authorized to operate by the city, state, or Interstate Commerce Commission (ICC), depending on where and how they run. The licensing authority largely is determined by geographic areas involved (interstate, intrastate, or totally within the city); the nature of the services (designated routes and stops, prearrangement); in some cases, the size of the vehicles used; and the intent of the operator to earn a profit (or not) by providing the services.

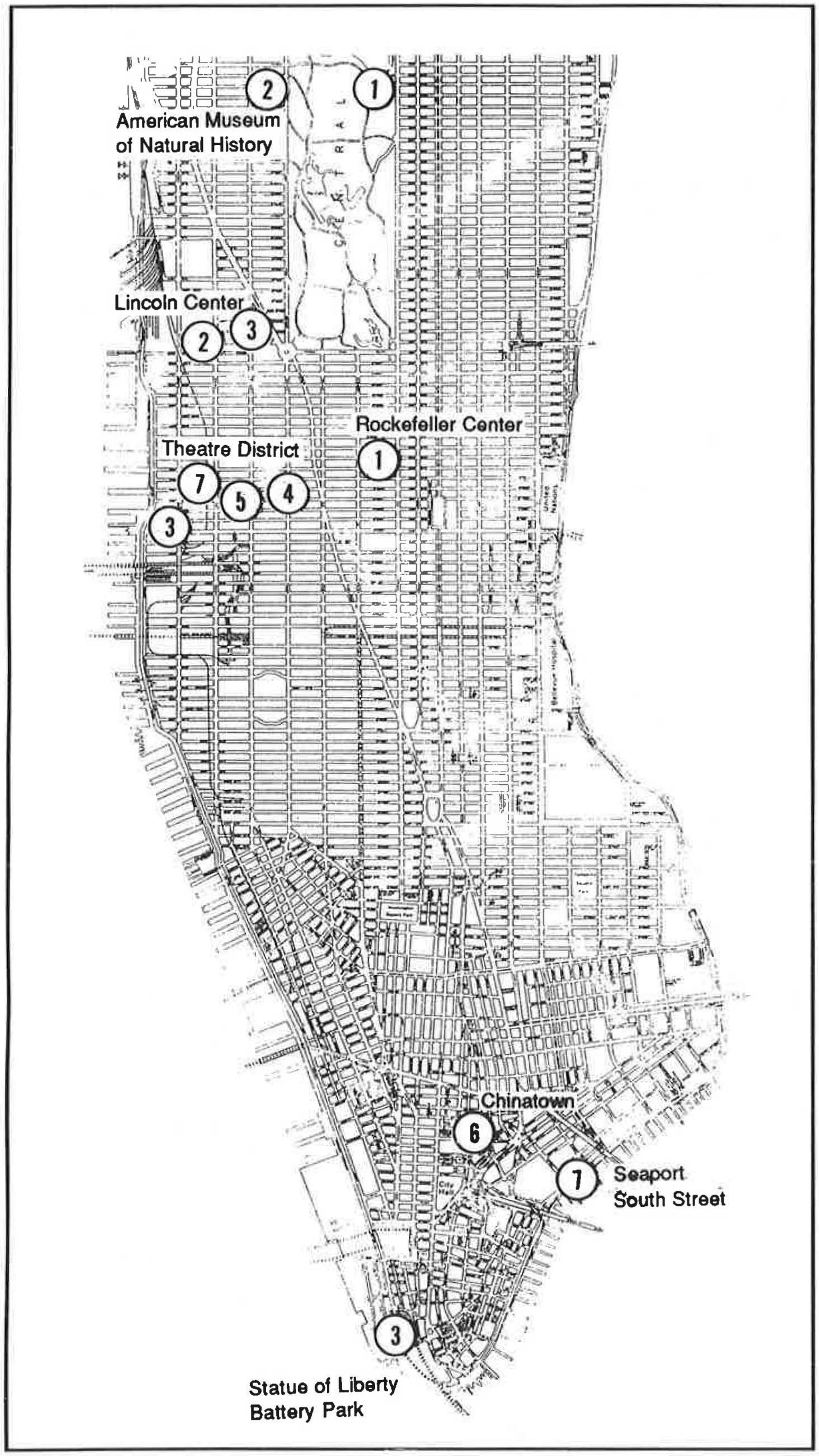
Collectively, the federal, state, and city agencies impose regulatory requirements that cover entry, exit, fares, service, and safety. Objectives include meeting transportation needs, minimizing street congestion and environmental polluting, assuring passenger safety and general fitness, and minimizing entry restraints and competition with city transit services. Methods of regulation used by the agencies range from simple application forms (ICC) to elaborate application requirements with multiagency reviews (New York City). The time needed to get an answer varies from several months (ICC) to several years (New York City).

The need to determine the best ways to control buses on city streets results in continuing discussions among the various regulatory organizations at the three levels of government. City, state, and federal agencies have disagreed with each other's interpretation, administration, and enforcement of the applicable laws. In particular, New York City and the ICC have conducted a continuing dialogue on traffic congestion and air pollution problems associated with interstate bus service. The city believes that these problems have been exacerbated by the commission's unwillingness to impose operating restrictions on ICC authorized carriers that provide local services.

Federal Government

The ICC regulates surface passenger carriers under the Bus Deregulation Act of 1982 as amended by the Surface Transportation and Uniform Relocation Assistance Act of 1987 (*2*, *3*). The ICC licenses interstate passenger service as well as regular intrastate route service provided by an interstate carrier on the same route. The 1987 act (*3*) states that the "carrier can provide interstate transportation service under the (ICC) certificate only if the carrier provides regularly scheduled interstate transportation service on the route."

Before 1982, the ICC's jurisdiction was limited to authorizing interstate services, and it was not able to authorize the use of local streets. Interstate buses were required by the city to use the Port Authority Bus Terminal to discharge and pick up passengers within city boundaries. An interstate carrier could use local streets for pickup and discharge instead of the



Key

1. No place to park buses
2. Inadequate bus parking
3. Inadequate signing
4. Buses block moving traffic
5. Buses load passenger from wrong side of street
6. Police cars preempt bus parking lot
7. Bus layover/parking areas are too remote

FIGURE 3 Observed problems with buses in Manhattan.

terminal *only* if it first obtained a franchise from the city. The franchise required that the carrier use routes and stops designated by the city (*4*).

The desire to foster competition in the transportation industry led to passage of the Bus Regulatory Reform Act of 1982 (the Bus Act), which dramatically modified the ICC's authority for regulating bus passenger service. The act (as incorporated in Subtitle IV, Title 49 of the *U.S. Code*) both expanded the ICC's jurisdiction and eased the criteria for obtaining ICC operating authority (*2*). Under the new provisions, the ICC can grant intrastate authority for regular route service provided by an interstate passenger carrier; however, this provision does not apply to charter and special operations.

Thus the 1982 Bus Act permits a carrier without a local franchise to pick up and discharge on local streets. Although the ICC has the authority to designate the route that a carrier must follow within a city, this rarely happens. Carriers in New York City therefore follow routes that they establish unilaterally (in many cases, Fifth, Sixth, and Madison avenues), stopping wherever they choose and laying over during the day on local streets, often with their engines idling. Although New York City regulations require that all bus companies obtain NYCDOT approval for routes, stops, and layovers, there is little compliance by the ICC-licensed carriers. Issuing summonses for noncompliance has not been a strong deterrent (*4*).

The ICC has interpreted the 1982 act to cover intrastate applicants, allowing the holder of an interstate certificate to provide intrastate service along a portion of the authorized route while leaving the interstate portion dormant. The commission's position gave support to those bus companies that applied for and received, but did not use, the interstate portion of their certificate. This issue is perhaps the point of greatest conflict between the ICC and New York City (*5*).

New York City administrators believe that the ease of entry permitted by the act and the absence of ICC-imposed operating restrictions on ICC-authorized carriers have compounded the city's street congestion, contributed to air quality and other environmental problems, and created unfair competition with publicly subsidized carriers. ICC-authorized bus services circumvent the city's franchise review process that balances service needs with environmental, air quality, congestion, and similar concerns.

Partially in response to the city's concerns, the Surface Transportation and Uniform Relocation Assistance Act of 1987 clarified the ICC's jurisdiction over intrastate bus services. Section 340 of this act allows a carrier to operate intrastate service under its ICC grant *only* if it provides regularly scheduled interstate transportation service on the same route (*3*). This limitation applies retroactively to all certificates issued under the 1982 Bus Act.

The ICC's forthcoming ruling on the Fun Bus case in California will have important bearing on future interpretations of this law. In this case, the decision of the Ninth Circuit Court of Appeals found that the ICC could not give intrastate authority to companies that have nonrelated interstate operations. Accordingly, the court remanded the ICC to reevaluate this case in June 1987. As of mid-1988, the case was being re-evaluated by the ICC (*6*).

New York State

The New York State Transportation Law gives the responsibility for regulating "for hire" transportation of passengers to the State Department of Transportation (NYSDOT). It regulates intrastate common carriers that operate in and out of New York City as well as contract carriers (charter service) that operate wholly within the city. The 1984 amendments to this law reflect a mild privatization philosophy (*7*). They ease entry and exit requirements along the lines followed by the ICC; however, the law retains a standard relative to public convenience and necessity. NYSDOT requires an applicant to submit evidence of need for a proposed transportation service, and the agency bases its final decision on the quality and quantity of public statements supporting need (*7*, Chapter 635). In contrast, the ICC presumes need, leaving to any protestant the task of proving otherwise.

The 1984 State Transportation Law 34 gives New York City full control over bus lines that operate totally within the city, whereas the state governs those carriers that operate between the city and other counties. The city's ability to influence the state in the granting of intrastate operating authority to a specific carrier is essentially limited to filing a petition in support or opposition.

As a result of the efforts of New York City officials, the 1984 law requires the state to take into account certain concerns important to New York City. Under Section 154 of the 1984 State Transportation Law, the state must consider testimony on the adequacy of existing mass transit and impact of the proposed service on mass transit. Furthermore, if a license is granted, New York City can require the state to incorporate the city's route requirements into the state license. NYCDOT requested that new bus lines be prohibited from operating on Fifth and Madison avenues, and the state continues to cooperate in this action (*4*).

New York City

New York City has jurisdiction over bus lines that operate entirely within the city, except where these lines form part of interstate service. The New York City Charter (Chapter 14) gives the Board of Estimate responsibility for granting franchises for bus services within the city (*8*). The Department of Planning oversees the Uniform Land Use Review Procedure (ULURP) with regard to proposed bus routes, and NYCDOT is responsible for street traffic controls and enforcement activities (some enforcement also is provided by the Port Authority of New York and New Jersey).

The process of granting franchises, as set forth in the New York City Charter, includes an application and review procedure. The Board of Estimate (*8*) "shall have the control of the streets of the City . . . and shall have the exclusive power in behalf of the City to grant franchises or rights or make contracts providing for or involving the occupation or use of any of the streets of the City . . . " (§362). Any franchise contract that is approved by the Board of Estimate is subject to the additional approval of the mayor and is not valid unless approved by him within 60 days after it is presented to him (§373).

To implement this mandate, several city agencies must produce information, perform evaluations, and make recommendations in a lengthy review process. The agencies involved include NYCDOT and the city's departments of City Planning and Environmental Protection. A City Environmental Quality Review Process (CEQR) is conducted for each route to identify any significant environmental impacts. Following this view, the Board of Estimate, acting with the help of the Bureau of Franchises and recommendations from participating agencies and intended entities, authorizes (unfranchised) buses to operate in New York City.

The basic objective underlying the franchise review process is to provide needed transportation services without overcrowding streets, undermining existing transit ridership, or degrading the environment. The time required for a franchise approval or decision may be as long as two years. Because of the long period involved, some carriers circumvent the process by applying for an ICC certificate.

The regulation of buses by New York City differs dramatically in almost every respect from regulation by the state and ICC. More agencies are involved, the concerns are greater, and the franchise review time is longer. It is unlike bus regulation in any other city.

The federal government and most state and local jurisdictions have divorced regulation from the legislative process. However, New York City continues to rely on a legislatively granted franchise that is the result of evolution alone. By contrast, bus service in Boston and Chicago is regulated by administrative arms of the state with minimal involvement of other state and local agencies. The Washington, D.C., area has adopted regional regulation by a single administrative body. In each of these cases the regulators make decisions on the basis of published rules and standards (*5*).

OPPORTUNITIES FOR IMPROVEMENT

The current ICC and NYSDOT regulations have led to a growing number of buses operating on New York City streets. This continued proliferation of unfranchised (and franchised) buses will increase traffic congestion, competition for curb space, and erosion of rail transit ridership. The city has two basic policy choices in dealing with this problem:

- To restrict (and thereby discourage) additional bus services, perhaps by aggressively protesting new commuter services when warranted; and
- To accommodate (and hence encourage) additional buses, perhaps by providing a major off-street terminal in Lower Manhattan and improving layover space elsewhere.

Both courses of action have application. Short-term improvements can be accomplished within the existing legal framework. Long-term changes, however, will require new legal arrangements.

Short-Term Improvements

The Bus Deregulation Act of 1982, reflecting the spirit of the Congress, gives the ICC full authority over entry and exit of regularly scheduled interstate carriers, including their associated intrastate services. The city's role therefore became mainly a reactive one with regard to certification, but city officials can take other actions as well. They can regulate the use of streets with police power, enforce city regulations and levy fines, specify bus stops and terminal areas, and plan and develop new facilities. Within this context, the following short range actions should be pursued.

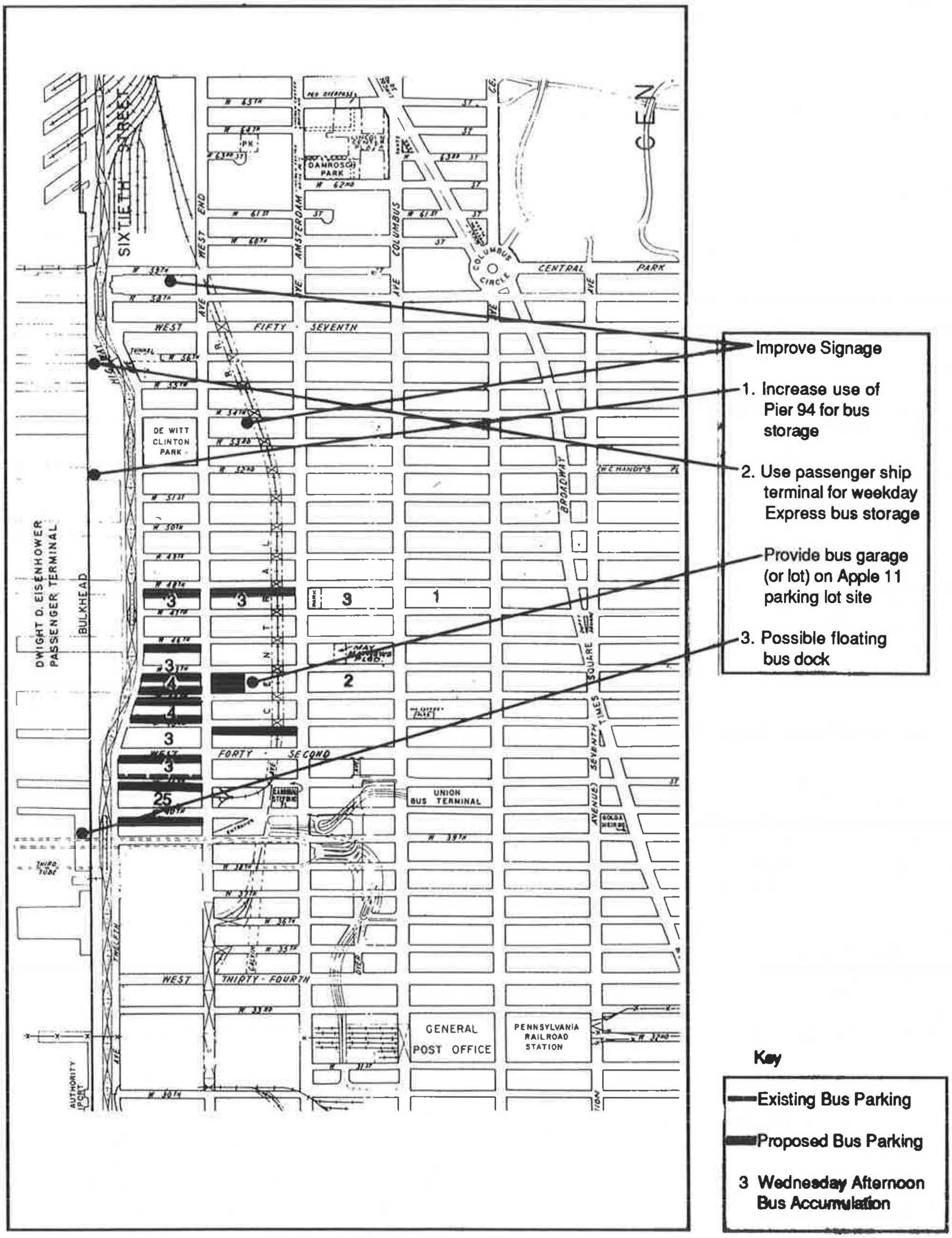
Traffic and Parking Improvements

Suggested traffic and parking improvements are given below and in Figures 4 and 5. Improved bus parking and layover facilities, especially at major tourist destinations, are noted. Off-street terminal and storage facilities in Midtown and Lower Manhattan are desirable to remove buses from city streets and to reduce deadhead mileage:

- *American Museum of Natural History.* Expand bus parking on west side of Central Park West, north of 77th Street adjacent to the museum. Progressively expand bus parking on east side of street between 77th and 81st streets.
- *Lincoln Center.* Expand bus parking on south side of 62nd Street by removing eight parking meters.
- *Theater District–Rockefeller Center*
  - *Short Term.* Establish bus parking areas on 48th, 44th, and 43rd streets; cross streets (48th–40th), mainly between 10th and 12th avenues. Improve enforcement and prohibit bus loading from the center of the street.
  - *Long Term.* Use first story of proposed "Apple" bus garage for tour and charter theater-bus parking (garage was proposed in a Port Authority sponsored study). Replace car parking with bus parking on Pier 94 at 54th Street. Consider "floating" bus storage dock in Hudson River.
- *Lower Manhattan*
  - Install 15–20-min time-limit signs along Battery Place for Statue of Liberty tour and charter buses.
  - Replace car parking with bus parking at the base of West Street. Charge buses to park in this area.
  - Replace car parking with bus parking under FDR Drive/South Street south of Fulton Street. Charge buses to park in this area.
  - Consider a bus terminal in Lower Manhattan, such as that proposed by NYCDOT for the Battery Garage site.
  - Incorporate provision for bus layover in the redesign of West Street.
  - Provide bus storage space along Park Row in Chinatown by enforcing curb parking regulations.
- *Fifth-Madison Avenues.* Reroute buses to other streets, but do so in a "nondiscriminatory" manner.

Zoning should require new developments that attract bus passengers to incorporate adequate space for buses. Accordingly, bus storage, layover, and "mini-terminal" facilities should be incorporated into the large scale developments planned for Manhattan's West Side, such as Trump TV City and New Madison Square Garden.

The city should prepare and continuously update a realistic traffic plan that controls the routing of *all* buses, especially in Manhattan. As part of this effort the city should continue to restrict new bus services on Madison and Fifth avenues,



Improve Signage

1. Increase use of Pier 94 for bus storage

2. Use passenger ship terminal for weekday Express bus storage

Provide bus garage (or lot) on Apple 11 parking lot site

3. Possible floating bus dock

Key

— Existing Bus Parking

▬ Proposed Bus Parking

3 Wednesday Afternoon Bus Accumulation

FIGURE 4 Theater District–Midtown bus storage plan.

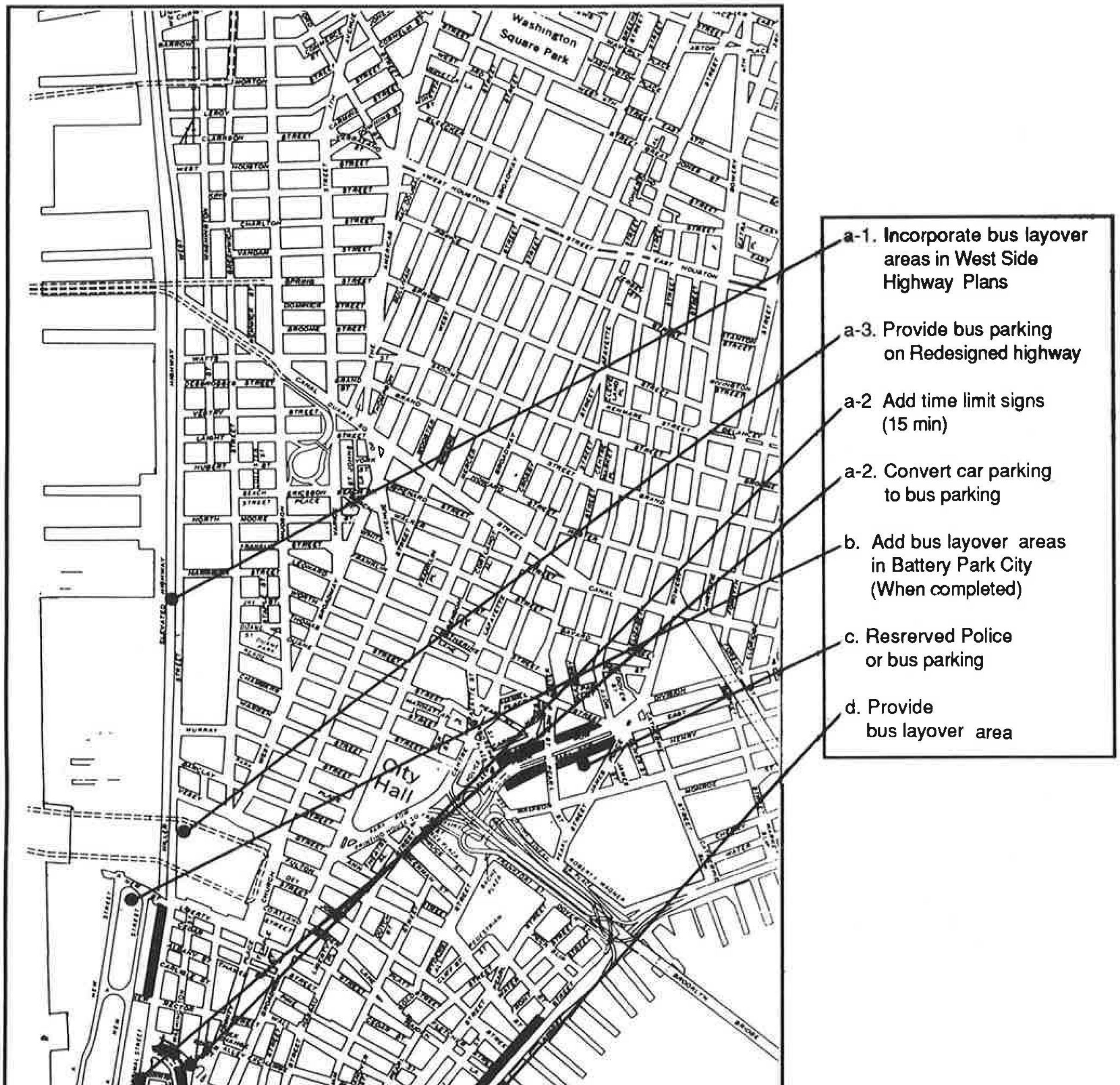


FIGURE 5 Recommended treatments for commuter and tour buses in lower Manhattan.

and it should encourage diversion of existing bus lines to some combination of Lexington, Third, Sixth, or Seventh avenues.

Improved Communications and Control

More effective communication with bus operators is essential to achieving better compliance with regulations and advising operators of planned changes. New, detailed brochures should clearly define routes, parking areas, layover practices, and fine schedules for violations at each tourist destination. NYCDOT, the New York Convention and Visitors Bureau, the Tourism Office of the New York State Department of Commerce, representatives of various tourist attractions, and bus operators should form a task force to develop this brochure.

The city should carefully control charter and tour bus operations by preparing specific rules of operation similar to those used by Atlantic City. Procedures should specify routes of travel; conditions for intercepting buses outside of congested areas; criteria for loading and discharging passengers, bus operations, and bus parking; and a graduated scale of penalties for specific violations.

Bus Franchising Improvements

The New York City bus franchising process should be improved and speeded up to better serve local bus operators and discourage circumvention of the process. Accomplishing these changes may require strengthening the Bureau of Franchises within the Board of Estimate or relocating the franchising authority elsewhere, within a mayoral agency or the Metropolitan Transit Authority (MTA). Placement in NYCDOT or in the MTA would permit coordination of franchising decisions with overall transportation policy. Placement in NYCDOT also would allow improved coordination of licensing, operation, and enforcement activities. Moving bus franchising from the Board of Estimate is a long-range activity because it would require a charter amendment. Streamlining the time-consuming franchising process, however, is an important first step.

Improved New York City–ICC Dialogue

The ICC should be encouraged to deny applications that are unwarranted from the city's perspective (*4*). Section 6 of the 1982 Bus Act requires that proposed service should be consistent with the public interest.

The Surface Transportation Uniform Relocation Assistance Act of 1987 indicates that interstate carriers are "authorized to provide intrastate transportation on a route under this (ICC) certificate only if the carrier provides regularly scheduled interstate transportation services on this route." The act gives the ICC a basis for limiting certain intrastate services provided by interstate carriers (*3*). This provision is expected to help limit the continuation and proliferation of specific "interstate" operations that mainly transport people between the outer boroughs and Manhattan. It also gives New York City a sound basis for protesting such services.

Accordingly, the city should promptly and vigorously protest new commuter bus applications pending before the ICC if these applications conflict with existing transit services or add buses to already congested streets. Protests can, and should, cover entry of carriers into the market, passage through New York City, and lack of designated routings in New York City. The ICC indicates that it is receptive to protests based on traffic congestion.

The city should request that the Environmental Protection Agency apply pressure to the ICC (and NYSDOT) about environmental issues (such as air quality). The city should also actively petition to have certificates of chronic violators of city traffic regulations rescinded. Operating authority should be invalidated when a carrier breaches city regulations.

New York City should work closely and cooperatively with the ICC (and NYSDOT) in reviewing and modifying routes. It should request that the ICC incorporate operating requirements into a certificate when granting authority.

Intensified Enforcement

New York City should apply its police powers more effectively and should intensify its enforcement activities. Police should control ICC- and NYSDOT-certified vehicles on streets and avenues, in curb spaces, and at bus stops, and the city should strongly enforce its regulations through surveillance and stiffer fines.

The city should have its broadened regulatory enforcement actions tested in court, as necessary, and it should encourage the ICC to revoke licenses for continued violations of city laws. As part of this effort, the city should be guided by the controls that it exerts over truck routes.

The broadened use of police powers is consistent with the city's proposed actions to meet federally mandated clean-air standards. To meet these standards, the state has set a State Implementation Plan (SIP). As part of this effort, the mayor announced several stringent measures to restrict vehicular flow and parking in Manhattan (especially south of 60th Street), increase the cost for cars to enter the city, and raise the penalties for noncompliance. Regulations that govern franchised and unfranchised bus travel might be included in the package.

Long-Term Opportunities

New York City should exercise greater control over applications for all new bus routes. The city should work to obtain new federal legislation that transfers certain ICC functions to the city or at least sets more specific requirements for applications. Congressional approval would be required.

Modification of ICC Requirements

Changes in ICC practices would give New York City greater control over bus operations on city streets. In particular, evaluations of requests for operating authority should consider congestion, pollution, and community impacts in determining consistency with public interest. The ICC should be able to deny an application on its own if the commission determines that the application is inconsistent with the transportation policy or other public interest factors.

A municipality (e.g., New York City) should be able to participate in hearings in which it has an interest. It should be able to require buses to use off-street terminals where such facilities are available. Moreover, where operating authority is granted, the certificate should be conditional on the applicant's obtaining approvals from an affected municipality for bus routes, stops, and layover areas. The ICC should be required to revoke a certificate at the request of a municipality where there is a chronic violation of these requirements.

Creation of an Exempt Zone

Creating an "ICC-exempt zone" is perhaps the best way to coordinate certification, impacts, and operational requirements. One possibility is establishing a New York–New Jersey bi-state compact that exempts all or part of the metropolitan area from ICC regulations. This type of compact has merit in theory. It recognizes the "metropolitan area" nature of a large portion of the interstate bus service between New York and New Jersey, and it builds on the notion of the Washington, D.C., Metropolitan Area Transit Commission (a multistate regulatory agency), as well as (in part) on another bi-state operating agency (St. Louis, East St. Louis). This compact, however, poses several problems that limit its practicality for New York City. It would require approval from New York State and New Jersey legislatures and governors, as well as Congress. Its authority would be vested in commissioners appointed by both states. New York City would probably represent a minority interest, and there is no assurance that the compact would reflect the city's position.

The preferable approach to rationalizing the unfranchised bus entry process is to create a New York City Exempt Zone that modifies the role of the ICC with the city. All entry and route applications for metropolitan area buses traveling to or from the city would be subject to ICC approval. Thus the zone would exempt from ICC control all Staten Island buses operating to Manhattan via New Jersey and all interstate buses with *both* origin and destination within the area of Port Authority jurisdiction or some similarly defined area. This zone has two desirable features. It is easier to implement than a bi-state agency because it is largely a matter between the city and the federal government, and it gives the city maximum control over commuter buses operating on its streets.

IMPLICATIONS AND EXTENSIONS

Transportation deregulation over the past decade has improved the operating environment for most carriers, but it has produced a mixed set of impacts for the "unfranchised buses" operating in New York City. Deregulation has facilitated entry into the market at no direct public cost, but it has removed the regulatory controls from the city, where most of the adverse impacts occur.

The city's lengthy franchising process and its difficulties in applying and testing its police policies contribute to this problem. The root of the problem, however, lies in the deregulation of interstate bus services, especially intrastate service operated by interstate carriers. Obviously, each of these areas needs corrective actions.

The Surface Transportation and Uniform Relocation Assistance Act of 1987 is a first step toward limiting ICC jurisdiction over intrastate carriers to those carriers that provide a reasonable nexus of service, but its impacts to date have not been clear. Additional legislative changes may be appropriate to redress the balance between local and federal control of metropolitan area interstate bus services. This is the authors' suggested direction for bus transportation deregulation in major metropolitan areas.

ACKNOWLEDGMENTS

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Critical Factors in Planning Multimodal Passenger Terminals

David W. R. Bell and John P. Braaksma

The critical factors for a multimodal passenger terminal policy for Canada were determined. The research methodology consisted of a literature review, data collection, and analysis. The data-collection phase used two questionnaires. The results of the first questionnaire, which was an open-ended questionnaire administered in Europe, Japan, and the United States, were used as input for a closed-ended questionnaire administered to all multimodal passenger projects in Canada. The results were analyzed by using paired comparisons of factor scores and an importance index. The results indicated that the critical factors, in order of priority, are integration of various modes of transportation, promotion of public transportation, cost of terminal, government cooperation, operating factors (safety, security, etc.), historical building preservation, environmental concerns (noise, air pollution), urban development, and reduction of local traffic congestion.

Multimodal Passenger Terminals (MPTs) are transportation centers in which several modes of transportation are physically and operationally integrated, usually under one roof. At an MPT, vehicles arrive and depart while passengers interchange among the modes in one terminal complex. These terminals can serve bus, rail, transit, taxi, automobile, ferry, and aircraft modes. Operational integration of modes could be accomplished through such methods as coordinated schedules, joint use of services, and fare integration. Intercity surface transportation and local transit operators, the traveling public, and the municipalities in some Canadian communities and provinces are currently interested in multimodal passenger terminals.

PROBLEM STATEMENT

MPTs appear to have certain potential benefits, but if their exact nature and extent in practice are to be determined, data from a number of operating MPTs will be needed. To develop operating MPTs, it was necessary to determine the factors that are critical in fostering successful MPT development. Determination of these factors was also required for formation of a policy that will create the climate necessary to develop MPTs in Canada. The critical factors for multimodal passenger terminals in Canada were identified in research carried out at Carleton University in Ottawa (*1*).

POTENTIAL FOR MULTIMODAL PASSENGER TERMINALS IN CANADA

There is substantial potential in Canada for developing multimodal passenger terminals. A study carried out for the Transportation Development Centre of Transport Canada identified potential sites for Canadian MPTs (*2*). This extensive study and analysis used such criteria as the number of modes, accessibility by time and distance, frequency of service by mode, and potential for expansion of existing terminals in terms of cost. In all, 131 Canadian urban areas with populations of 15,000 to 300,000 were reviewed. The study concluded that there were 14 cities with high potential and 98 sites with moderate potential. Numerous other studies and reviews have also established that there is good potential for MPTs in Canada (*3–5*).

CONCERNS

A number of concerns have restricted the development of multimodal passenger terminals in Canada. The first is the difficulty in bringing together the two major public intercity passenger modes, bus and rail. The bus industry believes that the considerable subsidization of the rail passenger mode puts the bus mode at an unfair competitive disadvantage. The Canadian bus industry is regulated by the provinces and is fragmented into some 60 separate companies, providing mainly regional service.

The second concern is that efforts to develop surface passenger terminals for bus and rail have been uncoordinated in Canada due to a lack of incentive to combine efforts. Each carrier prepares its own plans without consulting others. An incident from Saint Johns, New Brunswick, in 1979 provides a good example. VIA Rail consolidated a former Canadian National railway station and a Canadian Pacific railway station, located in the suburbs, into one downtown location. While VIA was preparing its plans, SMT, the major regional intercity bus carrier, was preparing plans for its own terminal at another location only a short distance away. This example illustrates a missed opportunity.

A third concern is the unknown scope and magnitude of any potential benefits. There has not been enough experience in Canada to define the benefits of MPTs. In the case of the Winnipeg MPT a cost-benefit study was attempted before development. The research could not be completed because the results varied with the assumptions on revenue gained through rental rates, tax incentives, passenger volumes, and

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so on. Another source of difficulty was the number of noneconomic benefits identified in the Winnipeg MPT project.

RESEARCH METHODOLOGY

The heart of the current research methodology was a literature review, followed by an extensive worldwide data collection effort. The data-collection phase consisted of the development and administration of two questionnaires. The first was an open-ended questionnaire, administered in France, Italy, the Netherlands, West Germany, England, Sweden, Denmark, the United States, and Japan. This first instrument was designed to develop factors for input into a second (Canadian) questionnaire. This second questionnaire, which was used to determine the important factors in the development of MPTs in Canada, was administered to representatives of all known Canadian MPT efforts.

The Canadian questionnaire was designed to be closed-ended. The respondents were asked to score the importance of each of the terminal development factors on a scale of one to seven, similar to a Likert scale. A low score was least important, and a high score was most important. This was not a priority ranking but an importance rating of each factor, independent of the others. This numerical scoring was then used for analysis.

ANALYSIS

The present analytical technique was based partly on studies conducted by Ross (*6*) and Cheung (*7*). Ross developed a method to rank the attractiveness of parks to a given type of user. The approach used origin/destination flows and data on the spatial interactions of individuals using 12 parks to produce attractiveness rankings for the parks.

Cheung used a similar method to develop a linear programming model that, subject to the constraints of air travel demand and aircraft capacities, allocates the origin/destination air passengers between two cities to the various feasible passenger routes defined for that city pair. Each of the passenger routes is assigned a weight to indicate its relative attractiveness. These weights actually represent penalties that the passengers incur in traveling from one place to another.

The method used in this research consisted of a paired comparison of the factor scores to determine the frequency of the score of one factor, *i*, exceeding the score of another factor, *j*. Analysis was performed with a computer program, and the resultant information was presented in matrix form. In the first matrix, the (i, j) entry is the number of times that factor *i* was judged to be more important than factor *j*. A second matrix was used to contain information on the number of times that two factors were judged to be equally important. These two matrices have the following properties:

$$C(i, j) + C(j, i) + E(i, j) = \text{total observations}$$

where

$C(i, j)$ = number of times that factor *i* was judged to be more important than factor *j*;
$C(j, i)$ = the number of times that factor *j* was judged to be more important than factor *i*; and
$E(i, j)$ = the number of times that factor *i* was judged to be as important as factor *j*.

A third matrix, formed by summing the first two matrices, indicated the frequency with which factor *i* was judged greater than and equal to factor *j*.

A fourth matrix was derived from the first matrix. The entries in this, the proportion matrix, gave the proportion of times that any factor *i* was judged to be more important than factor *j*. An entry in this proportion matrix is defined as

$$P(i, j) = [C(i, j) + E(i, j)] / [C(i, j) + C(j, i) + E(i, j)]$$

where $P(i, j)$ is the proportion of times that factor *i* was judged to be more important than factor *j*, and $C(i, j)$, $C(j, i)$, and $E(i, j)$ are defined as previously.

The proportion matrix was also developed for the percentage of time that factor *i* was equal to and greater than factor *j*. All this analysis was carried out three times: once for the responses from the communities, municipalities, and so on; once for the responses from the terminal planners; and once for the combination of the two.

To produce a relative ranking of the factors, an importance index was created for each factor by using the formula

$$I(i) = P(i, j)/n - 1$$

where

$I(i)$ = importance index for factor *i*;
$P(i, j)$ = proportion of times that factor *i* was judged more important than factor *j*; and
n = number of elements in the row.

To achieve $I(i) = 1$, it was necessary to use a constraint in $P(i, j)$: the elimination of $E(i, j)$ in the numerator and denominator. The factors were then ranked according to the size of the importance index, and a spread and gap were calculated for each interval. The spread is the ratio of the importance index in question over the largest importance index for that analysis, whereas the gap is the numerical difference between the spread from one factor to another in descending order of size. The spread provides an indication of the relative importance of each factor, as shown in Figure 1.

CRITICAL FACTORS

In priority order, the factors affecting MPT development in Canada were determined to be

- Integration of various modes of transportation,
- Promotion of public transportation,
- Cost of terminal,
- Government cooperation,
- Operating factors,
- Historical building preservation,
- Environmental concerns,
- Urban development, and
- Reduction of local traffic congestion.

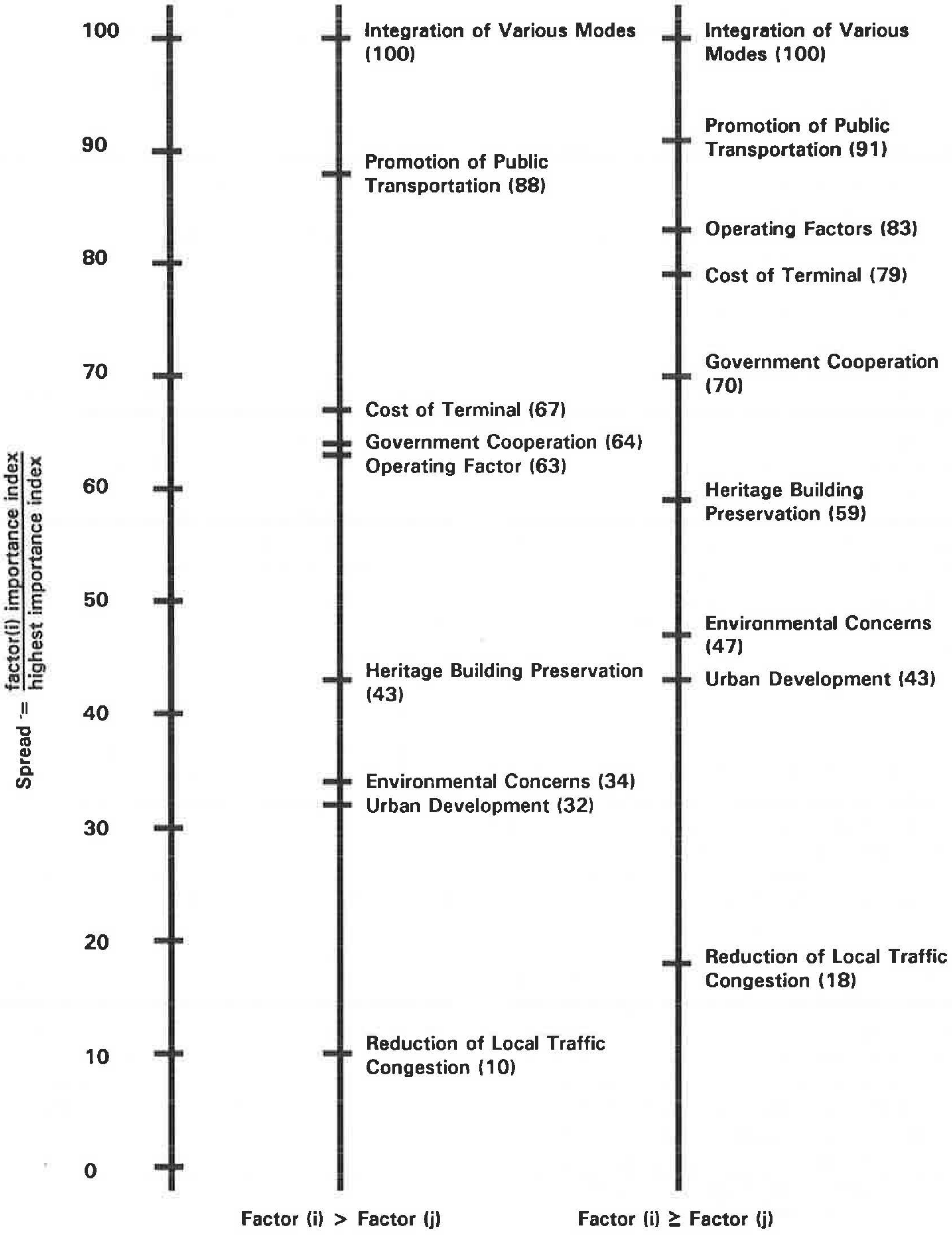

FIGURE 1 Display of relative factor importance.

VALIDATION

A modified Delphi technique was used to validate the results, which were also checked against two projects. These projects, one successful and one unsuccessful, were in Canadian cities of equal size with similar potential. The check suggested that the participants in the successful project were pursuing the more important factors, whereas the participants in the unsuccessful project were putting emphasis on the less important factors.

CONCLUSIONS AND RECOMMENDATIONS

In Canada, there is currently a pronounced lack of knowledge, literature, and research on the subject of MPTs. There is definitely a potential, however, for developing these facilities. Successful development of MPTs requires a policy that considers certain critical factors, in order of priority: integration of various modes of transportation, promotion of public transportation, cost of terminal, government cooperation, operating factors (safety, security, and so on), historical building preservation, environmental concerns (noise, air pollution), urban development, and reduction of local traffic congestion.

It is recommended that a policy be established to encourage the development of MPTs in Canada. A pilot project (or projects) should be constructed under the new policy. Finally, a research project (or projects) should be instituted to monitor any pilot projects.

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Use of Travelers' Attitudes in Rail Service Design

KIMON E. PROUSSALOGLOU AND FRANK S. KOPPELMAN

In this paper, an analysis framework in which attitudinal data are used to support service design decisions for a public transportation system is described. An analysis of the riders' ratings identified the rail service performance weaknesses that limit ridership. The identification of strong monotonic relationships linking objective measures of rail performance to rider perceptions made it possible to forecast the impact of service improvements on travelers' service ratings and on mode choice to predict ridership changes. The analysis framework provides transit agencies with a tool both to diagnose deficiencies in the service provided to travelers and to evaluate the ridership impact of service improvements and marketing changes aimed at increasing ridership levels. The framework was applied to Chicago area commuter rail service to demonstrate its feasibility.

In this paper, an analysis approach is developed to assist transit agencies in improving service design in an effort to increase rider patronage and farebox-generated revenue. The approach framework is based on the analysis of travelers' perceptions of the service attributes of rail transit and other modes and on the influence of these factors on travelers' choice behavior. This method extends previous approaches by developing a link between objective measures of service levels and travelers' perceptions of corresponding service attributes. These relationships are used to forecast the effects of service changes on riders' perceptions and ridership.

The traditional public transit agency approach has been to provide service at the lowest possible fares to attract or retain ridership. During the past decade, however, transit agencies have faced severe financial difficulties due to increasing operating costs, declining or stable ridership patterns, and decreasing federal and state funds for operating subsidies and capital investments. These factors have created increasing financial pressure and have forced transit agencies to seek ways to cover a greater share of their costs with passenger revenue (*1*).

The most common reaction of transit agencies has been to maintain low fares and reduce operating costs through cutbacks in the level of service offered. This practice, however, produces a negative pattern of ridership decreases in response to the reduced level of service. An alternative response to the transit finance problem is to combine improvements in the quality of service with reasonable fare increases. This approach will attract riders who are relatively insensitive to fare increases and are willing to pay higher fares in return for better levels of service (*2*).

The approach developed in this paper provides transportation agencies with a tool to determine whether low ridership is due to poor service or negative misperceptions among travelers, to evaluate and compare a set of alternative service and marketing strategies, and to select service designs that can be expected to produce larger increases in ridership.

DEVELOPMENT OF THE ATTITUDINAL APPROACH TO TRAVEL ANALYSIS

The models employed in transportation analysis to predict mode ridership evolved from models based on geographical aggregation to models that relate individual consumer behavior to characteristics of the alternatives available to the traveler. Early aggregate mode split models used the geographical zone as the unit of analysis and averaged across the observed behavior and the characteristics of individual travelers. The use of aggregate data and the lack of a behavioral basis for these models produced poor estimation results. These techniques also led to the development of relationships that were not correctly sensitive to policy variables and could not be used to support the decision making process (*3*).

In response to the limitations of aggregate mode split models, disaggregate econometric models were developed on the basis of theories of individual behavior. The use of the individual traveler or the household as the unit of analysis allowed the disaggregate models to reflect the underlying decision-making process of the traveler (*4*).

The specification of a traveler's utility function allows the researcher to

- Relate observed travel patterns to characteristics of alternative modes,
- Account for the effect of travelers' socioeconomic characteristics on their travel choices, and
- Consider the effect of situational constraints on mode choice decisions.

In comparison with the aggregate mode split approach, disaggregate econometric models enhance understanding of the determinants of travel choice behavior. It must be noted, however, that the disaggregate model structure also assumes that each traveler has full information about the available modal alternatives and objectively evaluates a limited range of modal attributes, leading to a choice based on maximization of the utility of using a particular mode (*5*).

It has long been recognized that the appeal of objects and personal values influence individual behavior but not necessarily in a rational way (*6*). Many transportation studies have identified nonobjective attributes as important determinants

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of travel choice (*7–11*). Choice models that are based on attitudes instead of objective measures overcome the limitations of the econometric approach by recognizing the role of travelers' perceptions, their imperfect information about modal alternatives, and the importance of a wide range of service characteristics, including some for which there are no objective measures. The use of travelers' perceptions thus offers better insight into consumers' decision process and allows the transportation agency to evaluate a broader range of potential strategies to influence consumers' choices and travel behavior, as explained by Koppelman and Pas (*12*).

Louviere et al. (*13, 14*) argued that travelers' choices are driven by their subjective evaluations of alternative modes. These choices are in turn affected by the objective characteristics of the system, which may be differently perceived by each individual. In the information-processing stage, various system characteristics are related to a smaller number of perceptual dimensions, whose relative importance determines travelers' preferences. During this process, travelers' perceptions are strongly influenced by their individual characteristics, their biases and normative beliefs, and the information that they have about alternatives.

The analysis framework described in this paper is based on the Consumer Oriented Transportation Service Planning framework (Figure 1), which was developed by Tybout et al. (*15*) for studying consumer responses to changes in transportation services. The model structure assumes that travelers' behavior expresses their preference, subject to the influence of situational constraints. Travelers' perceptions of their alternatives are directly related to their preferences and are influenced by performance characteristics of the system and individual psychological and social characteristics. These factors suggest that, from a transit agency perspective, travelers' behavior can be affected by changing their perceptions of the alternatives. In this context, the range of policy variables is not limited to service and fare changes but also includes marketing and promotional strategies that inform travelers of the attractive features of the transit service offered and modify their perceptions about those features.

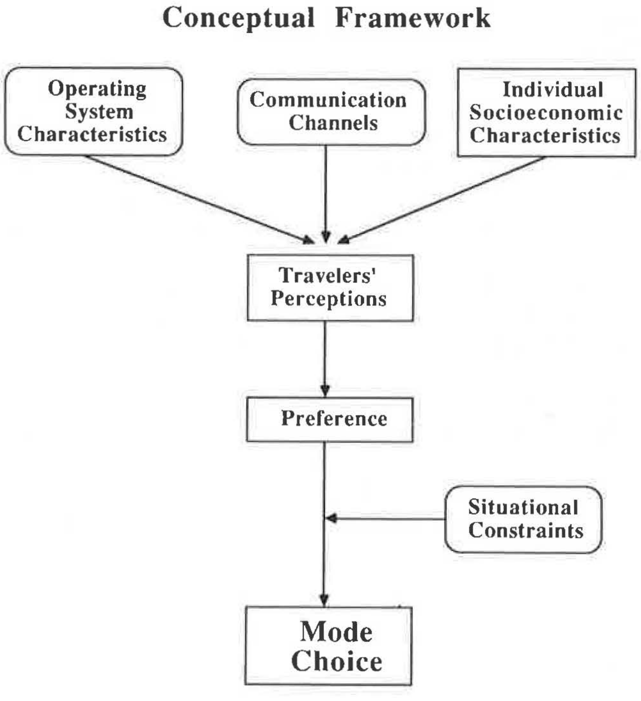

FIGURE 1 Conceptual framework for the consumer-oriented transportation service model (*15*).

APPLICATION OF ATTITUDINAL APPROACH TO SERVICE DESIGN

Limitations of Existing Attitudinal Models

The application of the attitudinal approach in a mode choice context enhances understanding of consumer behavior by including nonquantifiable aspects of the level of service as important determinants of mode choice (*16–22*). However, the drawback in attitudinal modeling is the lack of an essential link between objective measures of performance and subjective travelers' beliefs (*23, 24*). Because the actual performance characteristics are likely to have a strong influence on the formation of travelers' perceptions and are controllable by transit service management, it is essential to estimate how changes in level of service influence travelers' perceptions and consequently affect their observed behavior. This evaluation can be accomplished by developing relationships that relate objective measures of service performance to travelers' ratings of service attributes. These relationships can be used to forecast the impact of marketing actions and service improvements on travelers' ratings of service attributes and, consequently, on ridership levels.

Development of a Service Design Approach

In this paper, a service design–oriented framework is developed for use by transportation agencies as both a diagnostic and a forecasting tool. The method can be used to identify the aspects of service that most influence travelers' mode choice decisions and to evaluate alternative service design options.

The framework is developed by formulating relationships to quantify the influence of objective (engineering) measures of performance on travelers' perceptions of related service attributes. The relationships are based on measures of transit service performance that can be clearly related to riders' ratings of corresponding service attributes. These relationships are incorporated into a choice model that expresses mode choice as a function of travelers' perceptions. The choice model is used to forecast the impact of transit service improvements and thus provide managerially useful information on expected ridership responses to service and marketing changes.

SERVICE DESIGN BASED ON ATTITUDINAL ANALYSIS

Introduction

The service design–oriented framework uses travelers' perceptions of levels of service to

- Diagnose the perceived strengths and weaknesses of transit service, allowing identification of potential areas for service improvements, marketing strategies, or both;

TABLE 1 TRAVELERS' RATINGS OF CAR AND RAIL SERVICE ATTRIBUTES

Variable Name	Service Attribute	Rail Mean Rating	Car Mean Rating
QUICKLY	Getting to destination quickly	7.43	6.50
COST	Low cost	6.01	5.52
RELAX	Relaxing environment	7.33	4.84
SCHEDULE	Setting your own schedule to come and go as you wish	5.38	8.55
TEMPERATURE	Comfortable temperature	7.31	8.26
CRIME	Safety from crime	7.95	7.79
READ	Reading or doing paperwork	6.89	1.60
TALK	Talking with other people	6.01	3.39
CARRY	Ease of carrying briefcase, packages or papers	6.78	8.61
PRIVACY	Travelers' feeling of privacy	5.14	8.75
ACCIDENT	Little risk of accidents	8.20	5.13
ONTIME	Getting to destination on time	8.24	7.02
MINWALK	Keeping walking to a minimum	6.24	8.00
KNOWHOW	Transportation that I know how to use	8.13	9.06

NOTE: The 14 attributes of service are rated on a scale of 0 to 10, where 0 is poor and 10 is excellent.

- Develop a relationship between perceptions and service characteristics so that perceived weaknesses can be verified and the impact of service improvements on travelers' perceptions assessed;
- Identify the service attributes that have the most influence on travelers' mode choice so that direct service improvements or marketing strategies can be directed; and
- Evaluate alternative strategies by predicting the impact of transit service improvements on ridership.

To accomplish these objectives, data were collected on travelers' attitudes toward the level of service offered by automobile and transit alternatives. Such data can be gathered by using telephone surveys or printed questionnaires. Travelers' perceptions were reflected by their ratings on each of 14 service attributes (Table 1). Travelers were asked to rate each service attribute on a 0 to 10 or other scale in which higher ratings reflected more positive attitudes. Service ratings that reflected travelers' relative assessments were obtained for each alternative mode. Additional data were collected on travelers' socioeconomic characteristics, mode preference and choice, residence and work locations, and frequency of transit use.

In Figure 2, which is the flow chart for the analysis approach, each step of the analysis is related to the expected outcome and the corresponding actions to be considered by a transit agency. The following sections briefly describe how each of the outlined analysis objectives was accomplished by using the proposed analysis methodology. Then the results of an application of the methodology to the Chicago area commuter rail system (METRA) are presented.

Strengths and Weaknesses of a Transit Service

An evaluation of strengths and weaknesses of transit service as perceived by riders is obtained by comparing travelers' ratings of selected service attributes. These comparisons can be made at two levels: first, by identifying differences in travelers' perceptions of automobile and transit service, and second, by identifying differences among riders who use different portions of the transit system.

The comparison of mode service ratings is first used to identify service attributes that are perceived as good or bad over the entire transit system. Then, comparisons of riders' ratings for different portions of a transit system can be used to identify weaknesses and strengths on specific rail lines or bus routes. Analysis of variance can be used to test whether the observed differences in perceptions are statistically significant.

Objective Performance Measures Versus Riders' Perceptions

Relationships between objective measures of transit performance and riders' perceptions are obtained by associating riders' ratings of transit service attributes with measures of performance for different parts of the transit system. For example, the operating speed of a transit line can be compared with riders' perception of "going to destination quickly." These relationships allow the transit researcher to gain an enhanced understanding of the ways in which consumers' perceptions and behavior are affected by differences in the level of transit service. By using these relationships, transit agencies can also verify whether lower ratings reflect a lower level of transit service or are the result of riders' misperceptions about the level of transit service. Agencies can also select those measures of performance that most clearly reflect consumers' perceptions and can then design service improvements accordingly.

Identifying the Most Important Service Characteristics

A transit agency needs to focus its marketing and service improvement efforts on those aspects of transit service that are most likely to influence travelers' decisions to use the

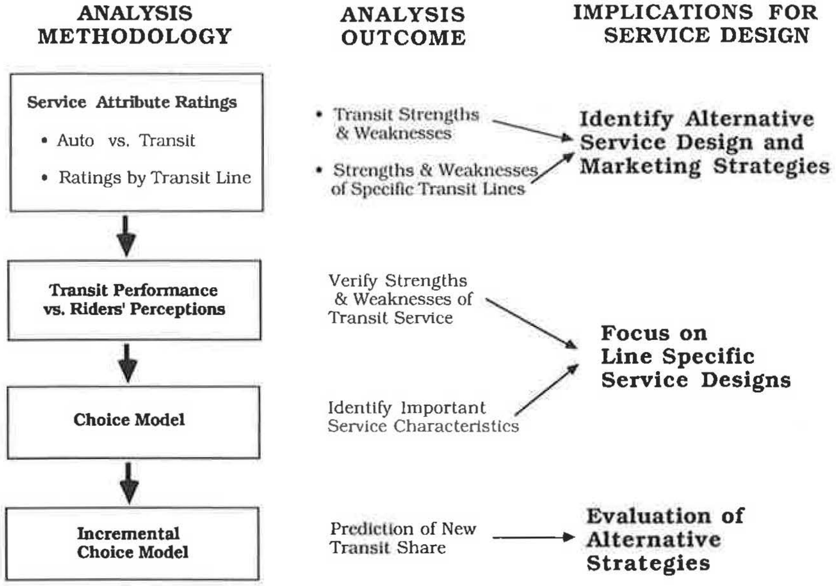

FIGURE 2 Overview of the analysis approach.

transit service instead of their own cars. The most important service characteristics can be identified either by the reasons that the travelers give as most important for choice of mode or by statistical analysis that links their mode choice to service attributes of the alternatives. The choice model that was developed for the current analysis relates travelers' mode choices to their perceptions of transit and automobile service attributes. The magnitude of the choice model parameters reflects the relative importance of aspects of service on travelers' choice.

Evaluation of the Impact of Service Improvements

The objective of a transit agency is to select, from the alternative strategies identified through the analysis of riders' perceptions, the strategy that is likely to be most effective in increasing rider patronage and farebox-generated revenues. The proposed forecasting framework relates service improvements to changes in travelers' perceptions and also relates changes in perceptions to an expected change in transit ridership levels. This approach can be used to forecast the impact on transit ridership of changes in the level of service offered or changes in marketing. A complete evaluation of the alternative options requires that both the feasibility of each set of service improvements and the costs associated with service improvements or marketing strategies be taken into account.

The incremental logit model used for these forecasts determines the impact of improvements in transit service, under the assumption that the level of service and travelers' perceptions of other alternatives are unchanged (*25*). The inputs to the model are the current market share of transit and the changes in travelers' perceptions of transit service. The output is the estimated new share of transit ridership that arises from the implemented service improvements. An implicit assumption of this formulation is that changes in the level of transit service are effectively communicated to all travelers through appropriate advertising and promotional strategies.

The predicted market share of transit, $S^{\text{new}}_{\text{transit}}$ is a function of the current market share, S_{transit}, and the change in travelers' perception of transit service, DU_{transit}, that is the result of service improvements:

$$S^{\text{new}}_{\text{transit}} = \frac{S_{\text{transit}} * \exp\,(DU_{\text{transit}})}{S_{\text{transit}} * \exp\,(DU_{\text{transit}}) + (1 - S_{\text{transit}})}$$

APPLICATION OF APPROACH TO RAIL SERVICE DESIGN

Analysis Context and Data Sources

The public transportation system studied in this analysis is the commuter rail system (METRA) in the Chicago metropolitan area. METRA is a high-quality radial commuter rail system that runs between the suburbs and the Chicago central business district (CBD). The system includes 11 rail lines that offer different levels of service. The peak hour daily ridership ranges from fewer than 1,000 passengers to 20,000 passengers.

The analysis is based on travelers' perceptions in two survey-generated data sets: an on-board survey of commuter rail riders consisting of ~4,000 observations across 10 METRA rail lines and a randomly selected telephone survey sample of ~1,500 suburb-to-CBD commuters. Both surveys were similarly structured and included information on the travelers' socioeconomic characteristics, their perceptions of the level of service offered by rail and other modes, and their chosen and alternative modes.

The large sample size of the on-board survey was used to make line-by-line comparisons and to develop relationships between objective performance measures and riders' perceptions. The telephone survey data were used to develop the mode choice model, which includes commuters' choices of automobile, rail, or other forms of public transit.

Strengths and Weaknesses of METRA Rail Lines

The average METRA rail and automobile ratings for the 14 attributes of service are presented in Table 1. Rail was rated

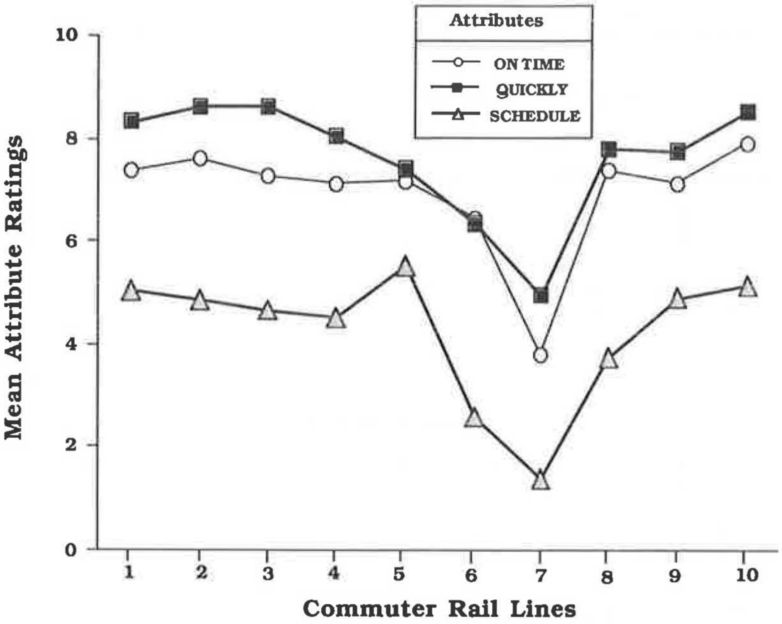

FIGURE 3 Riders' ratings by rail line.

superior to automobile in getting to destination quickly and on-time; cost of service; travelers' ability to read, do paperwork, or relax en route; travelers' ability to talk to others; and allowing travelers to feel safe from crime and accidents. On the other hand, automobile was rated higher in convenience and flexibility; ease of carrying a briefcase or packages; keeping walking to a minimum; providing a transportation system that travelers know how to use; providing comfortable temperature and feeling of privacy; and ease of setting one's own schedule.

This comparison suggests that the ability to read, do paperwork, or relax en route, along with the superior rail performance characteristics (speed, on-time performance, low cost) might be exploited in marketing METRA rail service and that a more frequent scheduling of trains and other changes meant to make riding METRA more convenient might be targets for service improvements.

It is also useful to compare the ratings of rail service given by METRA users with those given by drivers. Service attributes for which METRA riders' ratings are much higher than nonusers' ratings can be the focus of marketing or promotional strategies to "correct" the ratings of nonriders. Both strategies are aimed at improving nonusers' attitudes toward METRA with the expectation that some will shift to riding the rail system.

Among the same 14 attributes, riders on different rail lines gave similar ratings on the attributes of comfort, safety, ability to read and relax en route, and the social aspects of their everyday trip. Ratings differed across lines, however, for aspects of service that are closely related to rail operating characteristics, that is, flexibility in setting their own schedules (SCHEDULE), speed of rail (QUICKLY), and on-time reliability (ONTIME). A qualitative assessment of differences in riders' perceptions of level of service is provided by plotting the mean attribute ratings for aspects of service by rail line (Figure 3). These plots highlight important differences across lines. Lines 7 and 6, for example, are rated lower than all other lines for all three attributes. These two lines also receive the lowest ratings on overall satisfaction, indicating that it may be useful to direct service or marketing improvements at these lines.

A statistical analysis of riders' ratings of service across METRA lines supports the argument that differences in riders' perceptions can be primarily attributed to differences in performance characteristics across METRA lines. It can be concluded that ratings of attributes that correspond to service characteristics that can be controlled by METRA vary widely across rail lines. The association of these differences with objective measures of rail service by line is examined next.

Objective Measures of Rail Performance and Riders' Perceptions

Objective measures of rail performance were available for rail speed, on-time reliability, and frequency of service. Graphical and statistical approaches were used to investigate the relationships linking these measures of rail performance to riders' perceptions. The specific relationships examined were between

- The number of peak hour trains scheduled and riders' average ratings of the "ease in setting own schedule to come and go as desired,"
- The average delay per delayed train and riders' ratings of "getting to destination on time," and
- The average rail operating speed and riders' subjective evaluation of "getting to destination quickly."

For all three aspects of service, it was expected that riders' ratings would increase with increasing quality of service. In addition, ratings were expected to increase at a decreasing rate above a satisfactory level of service.

- *Schedule Flexibility* Given that the majority of METRA

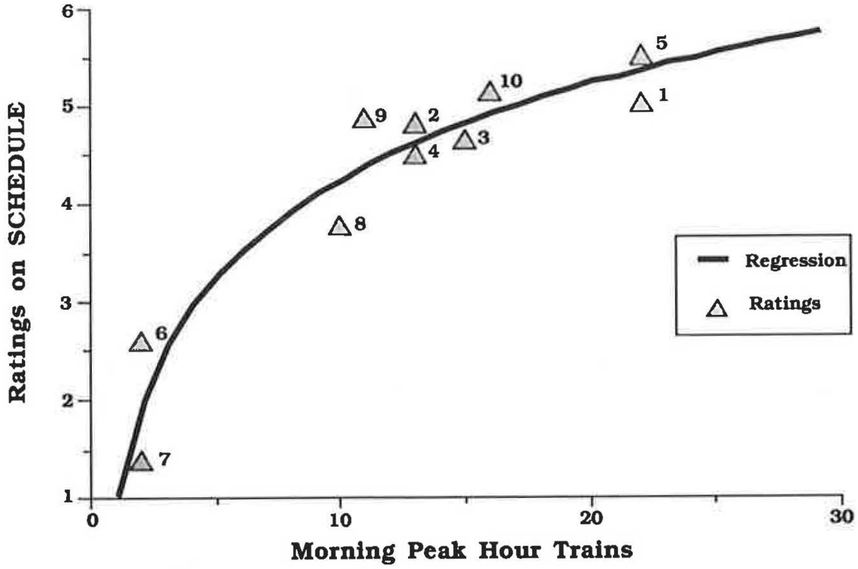

FIGURE 4 Perceptions of train frequency.

TABLE 2 MEASURES OF DELAY DURATION AND RIDERS' ONTIME PERCEPTIONS

METRA Rail Line No.	Riders' ONTIME Ratings	Trains On Time (%)	Delay per Late Train
1	8.32	98.34	13.0
2	8.59	98.58	10.8
3	8.60	98.67	11.6
4	8.04	97.02	11.1
5	7.40	95.63	15.5
6	6.33	94.61	16.5
7	4.97	96.47	16.9
8	7.80	96.19	11.8
9	7.76	96.60	11.7
10	8.52	99.69	4.5

riders' trips were daily work commutes, a comparison was made of riders' perceptions of ease in coming and going as they wished with the number of morning peak hour trains scheduled (Figure 4). The number of morning peak trains varied from 2 to 22. As shown in Figure 4, ratings on SCHEDULE have a strong monotonic relationship with the number of peak hour trains, and the relationship has a diminishing marginal form. The graph confirms that the reported differences in riders' perceptions were related to the level of service offered. Lines 7 and 6, which had only two morning trains, received a much lower rating than did other METRA lines.

- *On-Time Reliability* The commuter rail system in Chicago has a good on-time performance record, ranging from a low of 94 percent to a high of 99.7 percent of peak hour trains arriving at their destination less than 6 minutes late (Table 2). The ratings of ONTIME are weakly related to the percentage of trains more than 6 minutes late (Figure 5). A stronger relationship exists between ratings of ONTIME and the severity of delays expressed by the average delay per delayed train (Figure 6). Thus it was concluded that severity of delays is a more appropriate determinant of riders' perception of rail reliability than percentage of late trains.

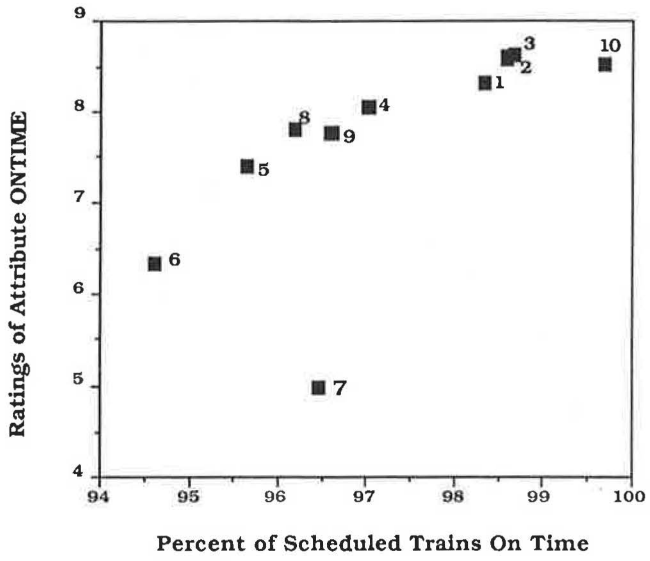

FIGURE 5 Delay frequency and riders' perceptions.

- *Getting to Destination Quickly* The relationship between average operating speed and riders' ratings of getting to destination quickly is not clear (Figure 7), but it does illustrate a strong basis for the poor ratings by riders of line 7. The absence of a strong monotonic relationship may be due to the influence of delays on riders' perception of getting to destination quickly. In addition, riders' ratings are quite similar for all lines with average speeds greater than 30 miles per hour. The high rating by riders for line 10, despite its low average speed, is probably due to its excellent on-time performance. These observations suggest that the current approach can be enhanced by developing associations between each service rating and several objective measures of service.

These relationships, which link riders' subjective evaluations to objective measures of rail service, provide a basis from which the transit operator can identify whether riders' unfavorable perceptions of aspects of rail service are due to

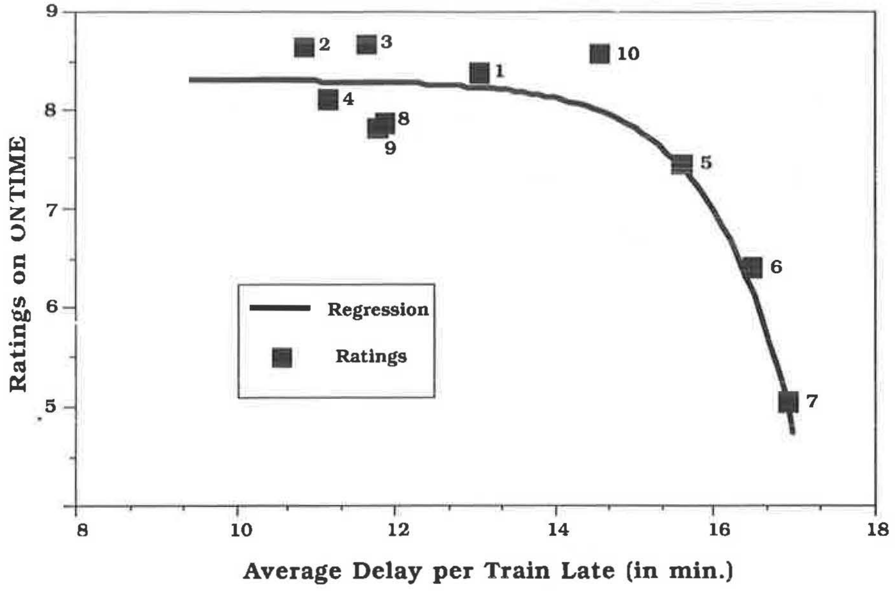

FIGURE 6 Delay severity and riders' perceptions.

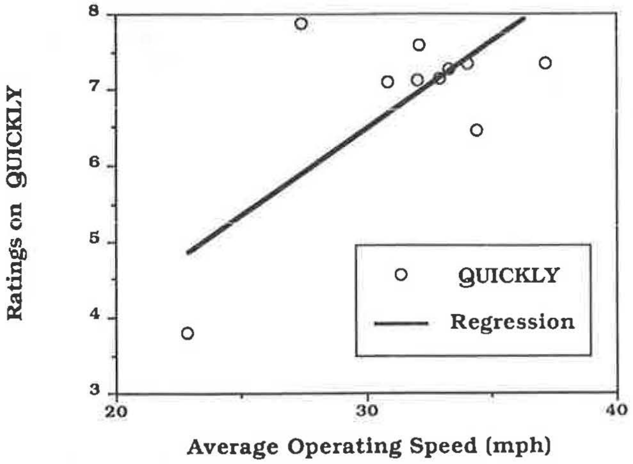

FIGURE 7 Assessment of rail speed.

a low level of service or to riders' misperceptions. These results could guide the choice between a marketing and promotional strategy to enhance the perceptions of positive attributes of transit service or service improvements to enhance the service provided. In addition, these relationships could be used to evaluate the impact of different levels of service improvement on riders' perceptions and, consequently, on ridership.

Importance of Service Characteristics

The relative importance of different service attributes can be used to direct transit management's attention toward those attributes that should be given high priority for service improvement. A random sample of suburb-to-CBD commuters, both METRA riders and others, were asked to rate the importance of each of the 14 attributes listed in Table 1. Rail riders and other public transit users selected performance characteristics (speed and on-time reliability) and feeling safe as their most important determinants of choice. Drivers placed high importance on schedule flexibility.

An alternative approach to determining attribute importance is to construct a model of mode choice behavior that relates the observed mode choice to travelers' ratings of aspects of service offered by commuter rail, private car, and other forms of public transit. The importance of service attributes in commuters' mode choice is reflected in the relative magnitudes of the model coefficients. The preferred model specification presented in Table 3 is consistent with travelers' stated importance but is more specific.

The resulting model specification is similar to traditional mode choice models in that it includes travel time (travelers' perception of QUICKLY), out-of-vehicle travel time spent walking to the station or the parking lot (minimum walk time: MINWALK), and out-of-pocket cost (COST of service). In addition, travelers' choices are also influenced by the ONTIME reliability of their alternatives, the ability to RELAX en route, and their familiarity with the transit system (KNOWHOW to use). Other attributes, including schedule flexibility, did not appear to be important in determining observed choice behavior.

Impact of Service Improvements on Ridership

The relationships developed in this section can be used to evaluate the ridership impact of selected service improvements. This approach is demonstrated by consideration of the effect of rail on-time reliability on rail ridership. Reliability has been recognized as an important determinant of mode choice, and relationships linking riders' ratings to actual rail operating characteristics were developed. The proposed approach is demonstrated by examining the effect on ridership of a reduction of average delay per delayed train to 14 minutes on lines 5, 6, and 7. The reported delay on these lines was greater than 15 minutes.

The forecast approach is based on the association of a change in expected service with riders' ratings of that service attribute and subsequent use of the choice model to predict mode shares on the basis of the revised service ratings. The choice model application is made at the aggregate level for each line by

TABLE 3 SPECIFICATION OF THE MODE CHOICE MODEL

Service Attribute Variables	Parameter Coefficient	t Statistic
Automobile dummy variable	1.23	8.4
Public transit dummy variable	1.55	5.8
Getting to destination QUICKLY	0.15	3.8
Ability to RELAX en route	0.14	4.4
KNOWHOW to use the system	0.14	3.2
Getting to destination ONTIME	0.11	2.7
Keeping walking to a minimum: MINWALK	0.09	2.5
Low COST of service	0.08	2.8

NOTE: All parameters are statistically significant at $a = 0.05$. Summary statistics: log likelihood, −318.4; likelihood ratio index, 0.421; likelihood ratio statistic, 462.6; percent correctly predicted, 82.9; degrees of freedom, 785.

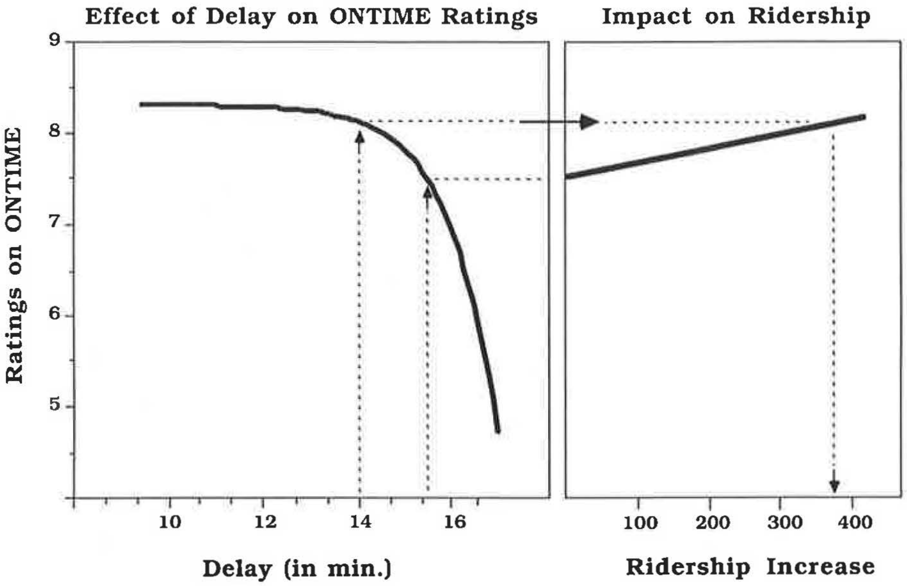

FIGURE 8 Impact of ONTIME improvements on ridership.

TABLE 4 RIDERSHIP IMPACT OF IMPROVEMENTS IN ON-TIME RELIABILITY

METRA Rail Line No.	Future ONTIME Rating	Future Market Share	Current Peak Hour Ridership	Future Peak Hour Ridership	Ridership Changes: Percent Increase	Ridership Changes: Rider Increase
5	8.20	0.71	13,131	13,508	2.87	377
6	8.20	0.45	640	726	13.48	86
7	8.20	0.49	1,641	2,026	23.48	385

using the incremental form of the logit model to reduce aggregation errors, as described by Koppelman (*25*).

The application of the prediction methodology is demonstrated in Figure 8 for an improvement in the on-time performance of line 5 from a 15.5-minute to a 14-minute average delay per delayed train. The relationship between objective measures of delay and riders' perceptions, as described previously, is used to predict riders' ratings for improvements in on-time performance level. Then the incremental mode choice model is used to predict the new market share of rail and the expected increase in ridership.

The expected ridership impacts (new ridership and change in ridership) for lines 5, 6, and 7 are presented in Table 4. The inputs to this analysis are the existing mode share and ridership and the existing and predicted user service ratings. The future ratings of service are estimated by using the target service level and the relationships that link riders' perceptions to service attributes. The future mode share is estimated by applying the incremental logit model, as illustrated in Figure 8.

The impact of a reduction of the average delay per late train to 14 minutes is shown in Table 4. The greatest percentage increases in ridership are forecasted for lines with the worst on-time reliability record (lines 7 and 6), whereas the greatest increase in actual ridership is expected for line 5, which serves a corridor with high travel volume.

Evaluation of Options

The demonstration of the methodology focused on forecasting ridership gains that are the result of service improvements. An integrated approach to service design requires that the cost of alternative options be considered along with technical considerations about the feasibility of the proposed improvements. Thus the complete analysis is able to focus on net revenue gains and can examine whether service improvements are justified by comparing the annual equivalent cost of the required capital investment with the increase in revenue.

Alternatively, the low price elasticity of commuter rail riders can lead to a policy of service improvements combined with fare increases, aimed at recovering part of or all the capital investment needed. The willingness of travelers to pay for the new service can be assessed by applying the prediction methodology to a range of fare and level of service combinations.

CONCLUSIONS

The use of attitudinal analysis approaches to guide transit agencies' service design decisions has been demonstrated in this paper. The preferred method is to use travelers' perceptions along with engineering measures of performance because the combination provides better insight into consumer behavior and therefore allows a better diagnosis of the problems facing urban transit. A transportation agency can use the enhanced understanding of travelers' behavior to identify a wide range of service improvements and marketing actions that can be used to attract ridership.

The policy value of the relationships that link objective measures of transit performance to riders' perceptions is their potential use as both a diagnostic instrument and a monitoring tool. Riders' perceptions can be used to diagnose weaknesses of specific transportation services, and changes in the level of service offered can be made accordingly. Similarly, for a high level of service, these relationships allow identification of riders' misperceptions. Responses could include appropriate marketing and promotional strategies.

As a monitoring tool, riders' attitudes can be used to ensure that level of service standards and riders' perceptions are maintained and to determine whether service improvements have produced the anticipated favorable changes in travelers' perceptions. The analytic framework applied in the case of urban rail transit also allows estimation of the impact of service improvements on ridership by comparing the estimated effects on ridership that result from the different options.

Priorities for service and marketing improvements are determined by identifying the importance of service attributes to travelers. Areas for concentrated efforts through marketing actions or service improvements are thus determined by identifying the service attributes to which travelers are most sensitive.

The feasibility of applying the analytic framework to public transit has been demonstrated in this paper. Monitoring the impacts of actual service changes provides a basis for validation and refinement of the methodology, allowing enhancement of the reliability of the conceptual structure.

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Driven, Attended, and Fully Automated Transit: Qualitative Comparison

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Three levels of automation of line haul, grade-separated, urban transit systems ("Metros") are identified for comparison: driven, attended, and fully automated. Comparisons are made among these levels in eight areas of service, safety, and dependability for line haul, grade-separated transit applications. Attended and fully automated systems nearly eliminate the human errors of a driven system. They also offer shorter headways, thus increasing capacity and service, allowing smaller facilities, or both. The stopping accuracies of attended and fully automated systems allow the use of platform doors, dramatically improving platform safety. These systems can have other benefits, such as reducing insurance premiums, minimizing operational disruptions, and providing a more pleasant waiting room environment. The ride comfort of the two automated levels can also be improved over that of driven systems. Fully automated transit outperforms both driven and attended systems in making schedule modifications, providing off-peak service, and managing failures. It also offers inherent resources for creating a more efficient administration of the system.

Much of the current discussion about line haul rapid transit in North America has concentrated on vehicle hardware (i.e., light versus heavy rail, rubber versus steel wheels, etc.). There is, however, a technical concern that is parallel and related, but often less visible: the level of automation of a system.

In this "high-tech" age, when half the homes in North America contain computers, use of automation has been relatively slow in coming to rapid transit systems. Originally, when many rail metros were first built, operations were performed manually, most often by using visual driving rules. Although trials of automatic electric block signals and trip stops date back to the 1860s and 1880s, it was not until World War II that color light automatic block signals, enforced by track trips (to enforce safe stopping), were routinely installed. This was the first instance in which automation overrode the function of the train's on-board operator.

It was the opening of the San Francisco Bay Area Rapid Transit (BART) system in September 1972, however, that marked the start of major new strides in the automation of urban transit metros. Although BART was originally intended to be a totally driverless system, it never reached that goal. Not until almost 11 years later, in May 1983, did the world's first fully automated (driverless) line haul urban transit system enter public service, in Lille, France. Two and a half years after that, the first major automated guideway transit (AGT) system in North America opened in Vancouver, Canada. In the United States the commitment to build the first line haul urban AGT system was made by the Los Angeles County Transit Commission on May 25, 1988. This system is scheduled to open in 1993.

Much has been written about how these fully automated systems are designed and operate, but comparisons among various transit concepts are frequently intermingled with questions of vehicle design, specific applications, cost comparisons, and so on. The purpose of this paper is to describe, in general terms, the progression of technical benefits claimed by increased levels of automation in the train control of grade-separated, line haul metros. Each level has progressively greater requirements on the redundancy of vehicle subsystems and the remote monitoring and control capabilities of the system. Only through an integrated understanding of all such design requirements and benefits can a proper, detailed cost-benefit tradeoff be made for any specific application.

A quantitative analysis of these benefits would require a much larger report. Furthermore, because fully automated line haul transit systems are still so new, the jury may still be out on some of the more subjective projections of the benefits of automation.

LEVELS OF TRAIN CONTROL AUTOMATION

The progression of automation in the train control of urban transit systems is subdivided here into three easily perceived categories.

Manual Systems

- *Driven* A one- or two-person on-board crew is responsible at all times for applying propulsion and brakes and for operating the doors. On some properties a limited degree of automation is used for safety. In these cases, automatic train protection (ATP) functions will override the crew's actions if they ignore certain safe procedures. Driven systems are typical of older rapid transit systems, such as those in Chicago and New York.
- *Attended* A crew member must be present to start the train, usually simply by closing the doors. He must also drive the train manually in the event of most system failures. Otherwise, the train's velocity between and door openings at stations are automatically controlled. The crew member may be an operator in the front cab, as in Paris and most newer systems (e.g., San Francisco's BART, systems in Atlanta and

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Scarborough) or can be a conductor/ticket checker in the passenger area (e.g., London Docklands).

Automated Guideway Transit

- *Fully Automated* No crew member is needed on board for normal and most failure recovery operations. These fully automated, grade-separated, line haul urban systems will be referred to herein as automated line haul transit (ALT). Lille and Vancouver are the only operational examples of ALT in the world at this time.

COMPOUNDING OF BENEFITS FROM AUTOMATION

There is a general concept that recurs throughout the following discussion of transit system characteristics. That concept will be referred to as the compounding of benefits from automation. This compounding of benefits occurs when the automation of one function facilitates a practical implementation of some other beneficial function or leads to potential cost savings in some other area.

Perhaps the best example of compounding of benefits on ALT systems evolves from an opportunity for more frequent trains at any given speed than is possible on driven systems. More frequent trains open up several opportunities for the operator of the system. Capacity can be increased, platform waits can be minimized, and smaller stations or vehicles can be utilized. This is an example of how a major improvement in a train control technical function ("separation") can provide a compounding of benefits in system characteristics that are directly visible to the public: higher service, lower capital cost, and lower visual intrusion. This improvement is discussed in greater detail in the later subsection on shorter headway.

There are also examples in which the automation of a train control function provides a compounding of benefits to other train control functions. For example, in any system, if a redundant or noncritical component fails on a vehicle, and that failure is recorded at central control, the affected train could be replaced at the end of the line. On driven and attended systems, however, this step is achieved only after communications have been made among central control, line supervisors, arriving and departing crews, and yard transfer crews (hostlers). Rather than be burdened with those procedures, central control personnel might leave the train in service and make a note for the maintenance department to schedule the repairs for that evening. In so doing, they may be risking an operational blockage from additional, and perhaps compounding, failures.

In contrast, in ALT systems the train with the failure can be replaced through simple keyboard inputs at central control, if spares in the fleet are available. The train would return to the maintenance yard automatically, where it might be repaired and returned to service before the day is out. To achieve this result, the fully automated vehicles must be equipped with more redundancy (to minimize disabling vehicle failures) and more detailed "health"-monitoring equipment (to detect the onset of problems) than is normally provided on driven or attended systems. Indeed, system/train interfaces become extremely critical to proper operation, and different automatic train supervision (ATS) is required, in comparison to that used with manual systems. In this example, automated fault detection in fully automated systems can trigger repairs within hours of a failure because of the fully automatic routing of trains. Even if the same level of automated fault detection were available in a driven or attended vehicle, achievement of an immediate response and maximum advantage of the detection would depend on a voice communication link and the availability of personnel.

Thus, although a more extensive communications infrastructure may not be unique to ALT, it is a logical tool that normally accompanies all such systems and offers more return on its investment than it would in manual systems. Through this communications infrastructure, ALT systems typically receive more compounding of opportunities and benefits from automation than do driven or attended systems. Several other examples of this compounding are mentioned in this paper.

The counterargument to this compounding of benefits concept is that the increased complexity of automation can be an added source of breakdowns (from causes that include computer malfunctions), with attendant disruptions to service and increased maintenance. It should be noted, however, that although there may be "teething problems" with the introduction of any new technology, the long-term resolution of the dichotomy between compounding of benefits and breakdowns from complexity lies in bottom-line operational experience. Some preliminary evidence is available from the world's first two ALT systems, and it favors compounding of benefits. For example,

- Lille's productivity per employee (146,000 passengers per employee per year) is close to double the average productivity of driven and attended North American systems.
- Vancouver's system is being extended to new stations, and Lille has opened a new ALT line this year. Both cities are continuing plans for other extensions, new lines, or both. In particular, it should be noted that Lille plans to replace an older yet successful LRT line with a third ALT line.
- The Lille maintenance facility is open only five days a week during conventional business hours, even though patronage is 50 percent higher than originally projected.

COMPARISONS OF PERFORMANCE CHARACTERISTICS

In general, there are eight performance areas in which a differentiation can be made between the three levels of automated train control. They are summarized in Table 1 and discussed in the sections that follow.

Elimination of Human Error from Train Movements

The elimination of human error from train movement was the original reason for introducing automation to transit. Decision-making actions that could result in errors by train operators and control tower personnel have been slowly replaced over the years with fail-safe devices. Initially these devices were pure hardware, but with the advent of voting

TABLE 1 PERFORMANCE COMPARISONS AMONG THREE ATC LEVELS

Factor	ATC Functions[a]	Best Performance		
		Driven	Attended	ALT[b]
1. Elimination of human error from train movements	P.1–3	*	**	***
2. Shorter headway	P.1		**	***
3. Platform benefits	P.4; O.2, 6		*	***
4. Ride comfort	O.1		***	***
5. Schedule modification	S.3			***
6. Off-peak service	S.1, 2			***
7. Failure management	S.5			***
8. Efficient administration	S.4, 6, 7	*	**	***

NOTE: * = some; ** = many; *** = most.
[a] Listed in Appendix A.
[b] Fully automated system, as defined in text.

microprocessors, fail-safe hardware-software combinations are now being used. Recently, fail-safe software has been applied to urban rapid transit (*1*).

Even though the fail-safe design requirement is normally not subject to tradeoffs with other design requirements, it is frequently confused with reliability. Reliability minimizes the frequency of failures. In contrast, fail-safe design ensures that virtually none of those failures, whatever their frequency, will create unsafe conditions. For example, the mechanical steering mechanism in an automobile is very reliable, but when it fails, the condition is almost certain to be unsafe. The vital relays used in the signal systems of railroad and transit properties also have very high reliabilities, yet they, too, may fail. In contrast, however, and more importantly, the design of vital relays and the restrictions on their installation and use virtually guarantee that no unsafe signal can be sent from the relay. Thus, given all the very infrequent failures that could occur in a vital relay, the probability that any one of those failures would be unsafe is so small (smaller than the probability of the failure itself occurring) that it is considered negligible.

In many older Metro systems the ATP system is very similar to that on railroads. A fail-safe signal is given to the train's operator or a switch-interlocking control person (or to both), but there is no insurance against human error, which is the most prevalent single factor in transit accidents. Full ATP can be added to driven systems and is inherent in attended and ALT systems. In systems with full ATP, human error as a safety hazard is virtually eliminated through fail-safe checks on the system operators in driven systems and by automatic fail-safe operation in attended and ALT systems.

Shorter Headways

Headway is the time between the successive arrivals of trains at a station. It is one of the most important parameters in the design of a transit system because within certain limits, shorter headways yield some combination of

- Increased capacity;
- Increased service (shorter waits);
- Shorter stations; and
- Smaller-diameter tunnels, narrower guideways, and tighter curves.

This last point encompasses several assumptions. Vehicle passenger capacity, for example, is proportional to gross floor area (typically, one passenger "place" is 5.4 gross vehicle floor area) (*2*). Tunnel diameters are a function of vehicle widths, and guideway widths are proportional to vehicle widths. Frequently, narrower vehicles are also shorter in length, resulting in closer bolsters, tighter turning radii, and smaller chording and nosing impacts on dynamic envelopes.

Perhaps more than in any other performance item discussed here, the design of short headways into ALT systems shows a compounding of benefits from automation. Driven and attended systems could be fitted with ATP systems that allow relatively short, safe headways at cruise speeds, but the determination of a system's minimum safe headway (MSH) is limited by the maneuvers and dwells of successive trains at online stations. Fully automated systems have shorter MSHs than manual ones because they utilize either a safe stopping velocity profile in each fixed block (as opposed to a single speed limit) or a moving block control system. Furthermore, transit systems cannot operate exactly at their MSH. Variances in the performance of the vehicles and the delays that can be imposed by ill, confused, or inconsiderate passengers require a margin to be added to the MSH of any automated or manual system. In manual systems an additional, larger time margin may be required to allow for variations in human responses, especially for driven transit systems. Thus the smallest achievable operating headways in transit are those on ALT systems, where 60 to 70 sec can be achieved with 50-mph line speeds. In contrast, driven systems at the same 50-mph speed with on-line station stops would normally be limited to 90 sec or more.

Attended systems can be designed to achieve the same low headways of fully automated systems but typically have not been, even on new systems. The reasons for this are not evident but appear to stem from the relative similarity between attended and driven systems. This similarity leads to acceptance of the small capital cost savings of longer headways (see Appendix C for a fully automated example) on the basis of the obvious rationale of driven systems: the longer the train, the more passengers one operator can transport. This reasoning becomes especially forceful when these trains are compared with the alternative of having the operator drive buses. With longer trains there is less need for shorter headways. Attended systems (light rail in particular) may also contend with automobile traffic at grade crossing or in mixed traffic. Although these locations may be limited in number, the existence of only one creates the weakest link of the system and can affect the headway, train length, trip speed, or level of automation of the whole line.

An interesting postscript to this discussion of transit headways is the issue of headways on city streets and highways. Normal automobile traffic operates under headways of 1 to 3 sec, whereas buses (3.5 sec) and street cars (5 sec) can operate at only slightly higher values (*3*). These values appear to present an opportunity for tremendously improved capacity over the transit systems discussed earlier, but there are three conditions that severely limit the performance of these street systems. First, these street headways are theoretical, and the time-averaging realities of traffic lights and crossing traffic are ignored in their calculation. The lowest average headways observed in actual operations for buses and street cars are 10 and 20 sec, respectively (*3*). Second, these headways are achieved at the lower speeds of city streets. Because vehicle stopping distances increase roughly with the square of the vehicle's speed, headways increase correspondingly for any transit mode, just by the laws of physics. Third and, perhaps most important, the level of safety on city streets is inherently lower than on fail-safe transit systems.

This safety issue is evident from an empirical comparison of the number of accidents and overall per-passenger safety records of street traffic, compared with fixed guideway transit systems. There is also a clearly identifiable engineering rationale behind this observation. The design of ATP-controlled fixed guideway transit systems has historically involved the use of a no-collision, brick-wall safety policy. That is, the automatic train control (ATC) systems are designed so that every train will maintain sufficient space between itself and its lead train so that it can stop safely without hitting the lead train (no-collision) if the lead train is assumed to make an instantaneous (brick-wall) stop at any time. The brick-wall assumption is a virtual impossibility, but because it is so conservative, it creates an extremely safe design environment. Drivers of street vehicles (including buses and streetcars) seldom enforce such conservative safety measures under peak capacity conditions.

Platform Safety

A number of intrusion detection and platform safety devices have been designed to detect or protect people on the track in platform areas. Vancouver has red panels between the rails that are electronically tuned to differentiate between the weight of a person and other, smaller objects on the tracks. Many systems have emergency power cut-off switches ("blue light" stations) that can be activated by patrons on the platform, but these switches have become targets for vandals in some systems. Safe refuge areas have also been built under platform edges. These techniques provide an added degree of safety but can never preclude an untimely fall, a suicide, or a blind person who mistakes a gap between cars for a door entrance. These unfortunate events will still happen. Furthermore, although vehicle alarm precautions are taken to prevent train doors from closing and locking on people or clothing, circumstances still occur which lead to the dragging, or at least terrifying, of patrons who are caught by the doors.

In contrast, on fully automated building elevators, though the door mechanisms are similar to those on transit systems, the magnitude of these safety problems are dramatically reduced. This is because two sets of elevator doors are used: those in the elevator car and those on each floor. On transit systems it is only through the highly accurate station stopping of automated systems that the elevator safety equivalent of double doors can be utilized. The use of station platform doors in Lille, France, for example, has been a major factor in achieving a perfect record of no injuries or deaths in the first six years of operation, even though a projection of such events from the Paris RATP system on a per passenger basis would predict several incidents each year in Lille.

Furthermore, the risk inherent to elevators of being trapped in the cabin in an emergency or power outage does not usually exist in ALT applications because of emergency walkways and egress through the platform edge walls of stations. These walls can be designed as a continuous row of doors, all readily openable from the vehicle or track side, as in Lille.

While safety is the primary reason for platform doors, or at a minimum, gates, other secondary considerations also exist:

- Liability insurance rates may be lowered by improved safety, perhaps even to the extent of paying for the capital cost of the doors;
- Platform edge safety widths may be reduced, thereby narrowing the waiting area and resulting in lower station capital cost and perhaps even lower visual intrusion;
- Large and small operational disruptions at platforms, from falling objects and nuisance blue light alarms, are minimized;
- Opportunities for vandals to generate graffiti on the outside of vehicles are reduced;
- Station heating and air conditioning cost savings during operation can be significant;
- Passengers can be protected from various guideway annoyances and hazards (steel wheel–rail noise, train airblast from tunnels, smoke in emergency fire situations, etc.); and
- Opportunities are increased for skip-stop or express operation through stations at higher speeds than are possible with open platforms.

Ride Comfort

Just as the automobile driving habits of some people can induce stress or car sickness in their passengers, so too do transit properties have problems in achieving reliable quality driving from operators on driven systems. The irregular driving patterns of train operators can tire or cause discomfort among passengers.

In contrast, automated systems are designed to have reliably steady acceleration and deceleration patterns that are often performed at very brisk rates. This automation can instill in the passengers a sense of efficiency, reliability, and confidence in the system. In fact, in this high-tech space and computer age, the reliable, crisp operation of automatic train operation ALT offers a rare positive image for public transit.

Schedule Modification

Although schedule planners try to anticipate the public's demand on a transit system, there will always be days or hours of unexpectedly high or low demand. When trains are driven or attended, the addition of one train may be impossible because of crew availability. Similarly, the deletion of unanticipated surplus trains is usually not even considered because the marginal cost savings is so small. There is an unavoidable cost for the crew that has already reported or, at least, is scheduled for work.

These are not problems in most fully automated systems. The calling of extra trains into service or deletion of trains from scheduled service is achieved via simple keyboard inputs at Central Control. After an addition or deletion, scheduled train dispatches can be routinely adjusted to distribute the new number of trains uniformly throughout the system or to group several trains into a bunch at shorter headways to run them through the system as an intentional "pulse" of higher capacity.

Off-Peak Service

Similarly, in midday and late night hours, the frequency of service of manual systems is limited primarily by labor scheduling and costs, not vehicles. In contrast, on automated systems the frequency of service can be easily increased with only small marginal cost impacts. The resulting convenience for passengers can attract greater off-peak patronage, lower the security risk of the station wait to users, and generally improve the overall usefulness of the system in the eyes of the public.

Failure Management

Delays that cause trains to fall behind schedule are typically addressed first by the use of progressively more severe schedule maintenance techniques. These include:

- Shortening station dwells;
- Using higher, but still safe, speeds (if available) between stations;
- Slipping the schedule of other trains; and
- Skipping selected stops.

In these schedule maintenance techniques, passengers continue to use the train because the delay was caused by an external problem or a failure that was not related to safety on their train. The train can be replaced at the end of the line, if necessary. All of these techniques can be included in the train supervision of any driven, attended, or automated system. They can usually be performed more quickly in an ALT system, however, because most of the central control and automation tools needed to implement the techniques are inherent to the ALT system. This is another example of the compounding of benefits from automation, as discussed previously.

When schedule maintenance techniques are insufficient to deal with an operating delay, or when a safety risk is involved, the failure management function must take over. The intent of failure management is first to get the passengers to safety (usually at stations) and then to remove the problem train from the main line as quickly as is practical so that service may be restored. Here again, there is a hierarchy of increasingly severe techniques, typically including

- Skipping some or all stops (after unloading passengers);
- Being pushed or pulled by another train;
- Intervention by emergency repair crew; and
- Being towed away by an independently powered maintenance vehicle.

ALT systems offer the opportunity for the first two of these techniques to be implemented more quickly than in either driven or attended systems, which require formal communications, perhaps the opening and initiation of manual control panels, and cab changes. Furthermore, as mentioned in the section on compounding of benefits from automation, ALT vehicles are designed for fewer disabling failures.

Efficient Administration

As transit systems are required to be more cost effective, questions of reliability improvements, maintenance planning, and general administration efficiency become more pressing. The success of each of these can be heavily influenced by the availability of the right data from a management information system (MIS). The MIS in turn is only as good as the freshness and quality of its source data. Because the communication infrastructure usually provided with AGT systems is typically quite extensive, the addition of specific record keeping and information processing functions within the MIS can often be implemented simply by adding software or minimal new hardware interfaces. Although a similar data-gathering system could be provided for driven or attended systems, such a modification might mean added capital cost. Those costs might be small, but the changes that incur them are likely to be viewed as "niceties" rather than "necessities," so such additions are therefore thought to be incompatible with the original rationale for selecting technologically simpler systems. Thus sophisticated communications are frequently not provided on simpler systems, and as a result, record keeping in AGT systems becomes an example of compounding of benefits from automation.

COST POSTSCRIPTS

The technical comparisons just made are one part of the larger question of how to select a transit system for a city. That larger issue is dominated by cost concerns. A brief perspective discussion on costs is provided in Appendix C.

CONCLUSION

The comparisons presented in Table 1 demonstrate that fully automated ALT systems have several significant performance, safety, and dependability advantages over both driven and attended transit systems. ALT systems represent a technically preferable alternative to more conventional driven and attended transit systems for those cases in which medium- to high-capacity transit that offers high-quality service (in terms of travel times and service frequency) is desired.

APPENDIX A: TRAIN CONTROL TERMINOLOGY

Train control is classically divided into three major functional groups (*4*):

- *Train Protection* The prevention of collisions and derailments.
- *Train Operation* The control of train movements between, and stops at, stations.
- *Train Supervision* The direction of train movements in relation to each other, route alternatives, a schedule, or any combination of those factors.

The typical functions performed within each group are as follows. Additional, related functions that may be performed by the transit system's associated communications and supervisory control and data acquisition (SCADA) networks are also presented.

- Train Protection—Tracking:
  T.1. Location,
  T.2. Direction, and
  T.3. Speed;
- Train Protection:
  P.1. Separation enforcement,
  P.2. Merge conflict resolution,
  P.3. Overspeed protection—(a) civil and (b) slow order,
  P.4. Guideway intrusion detection,
  P.5. Door operation/train motion interlocks,
  P.6. Platform/vehicle door position interlocks, and
  P.7. Switch lock protection;
- Train Operation:
  O.1. Speed regulation—(a) profile control, (b) cruise, and (c) separation,
  O.2. Station stopping,
  O.3. Door open control—(a) platform side and (b) location/zero speed,
  O.4. Dwell control,
  O.5. Routing (diverge control), and
  O.6. Alarm response—(a) immediate and (b) delayed;
- Train Supervision:
  S.1. Route assignment,
  S.2. Schedule dispatching,
  S.3. Schedule modifications,
  S.4. Schedule maintenance,
  S.5. Failure management,
  S.6. Fault detection, and
  S.7. Record keeping;
- Communications (Audio and Visual):
  C.1. Fire/police emergency phones,
  C.2. Passenger information,
  C.3. Security—(a) on board and (b) at stations, and
  C.4. Operations and maintenance;
- SCADA:
  D.1. Traction power monitor and control,
  D.2. Fare collection equipment monitor,
  D.3. Building intrusion detection,
  D.4. Tunnel ventilation control,
  D.5. Fire alarms, and
  D.6. Seismic and tunnel gas monitor.

The increasing use of automation in performing the train control functions has led to the common use of the following abbreviations:

- ATC: Automatic Train Control; and its subsets:
- ATP: Automatic Train Protection,
- ATO: Automatic Train Operation, and
- ATS: Automatic Train Supervision.

All train control automation is not the same. Different combinations of functions may be automated, and the levels of performance of the automation can be markedly different, usually depending on the technical sophistication. To automate safety-related functions, additional requirements for rigorous fail-safe design are added.

Given these three variations on the more than 20 ATC functions listed previously and the variations in design approaches taken among various manufacturers, it is not surprising that hardly any two transit systems have been automated in exactly the same way. Furthermore, recent momentum in Los Angeles and Houston, for example, indicates that individual cities may continue to design their own nonstandard systems. Los Angeles is moving toward the separate procurement of an LRT-compatible vehicle and a fully automated ATC, whereas Houston seems to favor a conventional turnkey fully automated system that has a manual operating mode.

In spite of these complexities, train control automation can be classified into three categories, ranging from little or no automation to the full extent of AGT. These are the three levels discussed in the paper: driven, attended, and fully automated.

APPENDIX B: TRANSIT TERMINOLOGY

One technical characteristic of transit systems has been explored in this paper: the level of automation in the operation of the trains. That categorization of transit systems differs somewhat from the more popular classifications (*5*) by

- hardware (e.g., light rail = modern streetcars set in a variety of rights-of-way),
- rights-of-way (mixed traffic, grade separated, etc.),
- technology (rubber tire, steel wheel, etc.), or
- service (regular, commuter, etc.).

Therefore a discussion of automation level with respect to current systems, practices, and terminology may be useful as a touchstone.

Typically, manual systems (both driven and attended) have been procured by using separate contracts for each major subsystem (vehicles, ATC, traction power, etc.). These systems generally fall into two categories, based loosely on carrying capacity and vehicle design: light rail transit (LRT) and heavy rail transit (HRT). Heavy rail is also sometimes referred to by the more generically proper term "conventional rapid transit" (CRT) to allow for alternate technologies (e.g., rubber tires).

In contrast, AGT systems (fully automated) are built under single contracts, with the system supplier providing all transit-related hardware. Sometimes, in "turnkey" contracts, even the guideway and station facilities are provided by the system supplier. This simplifies the contractual interface for the transit authority and puts the facilities design and construction risk into the hands of the system supplier instead.

Subcategories within the general AGT umbrella were defined by the U.S. Congress in 1975 (*6*) as shuttle loop transit (SLT), group rapid transit (GRT), and personal rapid transit (PRT). Unfortunately, however, that report did not allow for a fourth subcategory of AGT, which is referred to here as automated line haul transit (ALT). It is characterized by:

- line haul configurations,
- full automation (no drivers or attendants required on board), and
- high performance (higher speed than other AGT, lower headways than conventional transit, and medium to high capacity).

ALT includes the operating systems in Lille and Vancouver and the designs selected for Los Angeles, Taipei, Lyon, Bordeaux, Toulouse, and Strasbourg. In contrast, "people movers" in airports, activity centers, and amusement parks are usually better classified as SLTs or GRTs. One reason is their lower performance levels. Other considerations frequently include a lack of the characteristics required for urban applications (e.g., ease or speed of switching) or private ownership that excuses them from public requirements (e.g., fire or life safety standards). Anomalies and different opinions abound, however, in attempts to classify specific systems rigorously. Some experts refer to Vancouver's fully automated system as an LRT rather than an AGT. The new Century freeway system will probably use LRT vehicles procured under contracts separate from those for the ATC system, but will be a fully automatic system. UTDC's Intermediate Capacity Transit System (ICTS) has been installed as both manual ("attended" in Scarborough) and fully automated (ALT in Vancouver, SLT in Detroit) systems.

This paper sidesteps these differences in global definitions by concentrating on the one technical characteristic discussed earlier: the level of automatic train control. The determination of whether a system is driven, attended, or fully automated (as defined herein) is easily made, and the implications for performance, safety, and dependability discussed satisfactorily.

APPENDIX C: COST GENERALIZATIONS

ROW Cost

To physically build a rapid transit system, a city must have two prime resources, right-of-way (ROW) and funds. Ultimately, it is ROW, including real estate and civil structures, that sets an upper limit on the level of performance of the system. A truly grade-separated system adds all-new transportation capacity to a city. Any compromise on full grade separation not only limits the speed and capacity of the new system to something less than their fullest potentials but also places a new restriction on the capacity of the existing transportation infrastructure because of shared traffic lanes, prioritized signals, grade crossings, and so on.

Poor ROW can be improved by the funding of grade crossing eliminations, elevated structures, tunnels, and similar projects. These separate the transit system from the restrictions of street traffic but invariably translate into a need for more funds. Thus, early in the rapid transit planning process, each city faces a tradeoff between the quality of the transit system's performance and ROW and civil structure costs.

This tradeoff is the most significant issue in scoping the characteristics of a transit system. However, funding and ROW resources are political and urban issues. Although the tradeoffs between them usually result in restraints on the transit system, these restraints should not be confused with the innate technical limitations of various hardware systems. Separate understandings of political and urban concerns and technical issues are needed to properly select a transit system for a city.

For example, existing city streets offer the advantage of no ROW cost for the transit system but result in bus and streetcar transit systems, which are constrained to low performance by automobile traffic. Light rail offers flexibility in selecting a low level of ROW capital cost but at the expense of performance limits. The weakest link of a system, as mentioned in the discussion of shorter headway, is a grade crossing or a mixed traffic area. If these weak links are not eliminated because of cost constraints, the transit hardware is prevented from performing up to its full potential on other parts of the line. The extensive grade crossing–elimination program on the northeast rail corridor is an example of the need for increased safety and reduction in operating delays and personal property damage on an operating railroad system. The cost of those reconstructions is a testament to the cost premium to be paid when such modifications are not made as part of the original design.

It is only on fully grade-separated ROWs (elevated, tunneled, or fenced at grade without street crossings) that the maximum performance capabilities of all transit systems are unhindered. Unfortunately, the cost of achieving that grade-separation can vary significantly from city to city and even corridor to corridor. Whether the city has the ROW and financial resources available to achieve separation is a site-specific political and urban tradeoff. To divorce the site-specific tradeoffs from an understanding of the technical issues, fully grade-separated ROW has been the common ground assumed in this paper.

Within this framework of fully grade-separated ROWs, some generalizations about ROW costs are made. Automated systems can be used to allow shorter stations, smaller diameter tunnels, narrower guideways, and tighter turning alignments than are possible on equal-capacity driven systems and some attended systems, as discussed in the section on shorter headways.

System Capital Costs

In a subsystem-by-subsystem comparison, fully automated transit systems are expected to have a marginally higher capital cost than attended systems. For example, the 20-mile

Norwalk–El Segundo rail line of the Los Angeles County Transportation Commission is completely at grade and will be fully automated (7): "The additional cost of automation for the . . . line is $23 million, bringing the total to be spent on the rail project to $368 million." This 6.25 percent of the system cost would, of course, be a much lower percentage if the system had been elevated or tunneled (or both). Similarly, attended systems can be expected to have a higher cost than driven ones.

Primary Operating and Maintenance (O&M) Cost Issue

The most significant cost advantage of fully automated systems lies in the productivity of labor. When a crew member is required on each driven and attended train, a corresponding total of four or five employees are needed on payroll to allow for multiple shifts, vacations, lost time, hourly variations in the number of trains in service, supervision, and administration.

In contrast, automated systems eliminate the requirement for on-board crew and instead allow flexibility in selecting an employee on-board policy. This policy can be tailored to the passenger assistance, security, and ticket checking needs of the locale and hours of the day. Thus the staffing levels of attended systems represent a worst case, or upper limit, of the staffing required by an equivalent fully automated system in the same application. Furthermore, the on-board operating personnel required in manual systems are more technically trained (and hence may represent a higher salary level) than the fare collection, security, and information employees needed on a fully automated system.

In Lille, for example, although 12 employees are required for maintenance of the ATC system and 26 for ticket control, passenger information, and first-line fare collection equipment repairs, it is estimated that 102 additional employees would have been needed over the 1987 total staff of 185 if the system had been driven or attended. In terms of productivity, that would have changed the 146,000 passengers per year per employee to 95,000.

Secondary O&M Costs

Secondary O&M cost savings from fully automated systems have been identified, as follows:

- Shorter headways can mean a general reduction in ROW requirements, such as shorter stations, smaller tunnels and guideways, or tighter turning alignments. A portion of these changes translate into lower O&M costs.
- Platform safety can reduce insurance premiums, allow narrower platforms, and possibly reduce blue light and trackwork subsystems costs.
- Schedule modifications can save operating costs by easily tailoring service to demand without the restrictions of crew scheduling.
- Efficient administration can increase employee productivity.
- Off-peak level-of-service increases can induce additional patronage, thereby increasing revenues.

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Impact on Transit Patronage of Cessation or Inauguration of Rail Service

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Many theorists believe that transit service mode has little influence on consumer choice between automobile and transit travel. Others believe that they have noted a modal effect in which rail transit attracts higher ridership than does bus when other factors are about equal. Given environmental concerns and the large investment needed for guided transit, a better understanding of this issue is essential, especially for congested areas. A consideration of the history of automobile and transit travel in the United States can be helpful in comprehending the nature of the problem. After World War II, availability of vehicles, fuel, and tires spurred growth of both private automobile use and use of buses for transit. Analyses of the effects of both this growth and the improvements in rail systems that were added during the same period reveal that transit mode does indeed make a significant difference in the level of use of a transit facility. This factor must be included in future alternative analysis studies if reliable patronage determinations are to be made.

The purpose of this paper is to analyze what difference (if any) rail transit makes in attracting the public to use public transportation. Many metropolitan areas in North America suffer intensifying traffic congestion with no cure in sight, particularly in the suburban growth areas (*1*). At the same time, air pollution laws and problems require a radical reduction in emissions, with no assurance that much improvement can be accomplished. Diesel transit buses will be among the first vehicles to be affected by the Clear Air Act in 1991, but the necessary technology has not yet been perfected. Urban air is still not sufficiently healthful.

The expanded use of public transit can sharply reduce the use of automobiles and resulting pollution. The consumption of only 700 gallons of motor fuel per household in the District of Columbia and New York State, where there are significant rail transit services in addition to ubiquitous bus services, is evidence of this. States with the least transit service consume nearly three times as much motor fuel per household as do states in which rail transit predominates (*2*).

Most traffic- and trip-generation studies recognize no difference in trip generation attributable to the choice between rail and bus service, although recent work by R. H. Pratt and the Metropolitan Washington Council of Governments (*3*) demonstrates that recognition of the difference has begun. In estimating commuter rail patronage, Pratt found it necessary to increase rail estimates 43 percent over calculations for similar bus service to calibrate models accurately for suburban transit use (*4*).

Earlier, the Delaware Valley Regional Planning Commission found that regional models calibrated for 99 percent confidence level grossly overstated local bus ridership and equally understated commuter rail ridership to obtain correct regional totals (*5*). There is thus considerable anecdotal evidence that transit submode choice can make a substantial difference in the actual attraction of motorists to transit, with widespread attendant benefits.

It is true that travel time, fare, frequency of service, population, density, and distance are all prime determinants of travel and transit use, but automobile ownership and personal income may not be consistent factors for estimating rail transit use for people with a choice. Most bus riders are heavily transit dependent, whereas subway passengers are less so. Railroad commuters are highly dependent on automobiles and high incomes to access and use rail service, and they do use it where it is of high quality (*6*). The same models do not appear to work accurately for the different transit submodes, but too few studies recognize the difference.

In this analysis, the historical secular trend in the transit industry from 1947–1948 to 1975 (when the statistical base was shifted to unlinked trips) will be examined first, to seek evidence of any differential in the rate of public use of public transit by submode. During this period, transit use fell from a post–World War II high to a low second choice for those who could not avoid it.

Next, case-specific changes from rail to bus service will be analyzed for cases in which data are available, with the aim of gaining a better understanding of the impact of these changes. Finally, changes from bus to rail service will be analyzed similarly. The results of these analyses will speak for themselves.

PAST TRENDS

After World War II, during 1947–1975, most transit systems were modernized to take advantage of less capital-intensive technology, expanding freeway systems, and suburban growth by substituting diesel buses for most electric railway services and some commuter railroad services. Electric railway vehicles in service declined from 36,377 in 1945 to 10,712 in 1975 (*7*). Commuter railroad coach requirements declined from an estimated 7,335 in 1945 to 4,438 (actual) in 1976. (An estimate had to be made for 1945 because railroads at that time did

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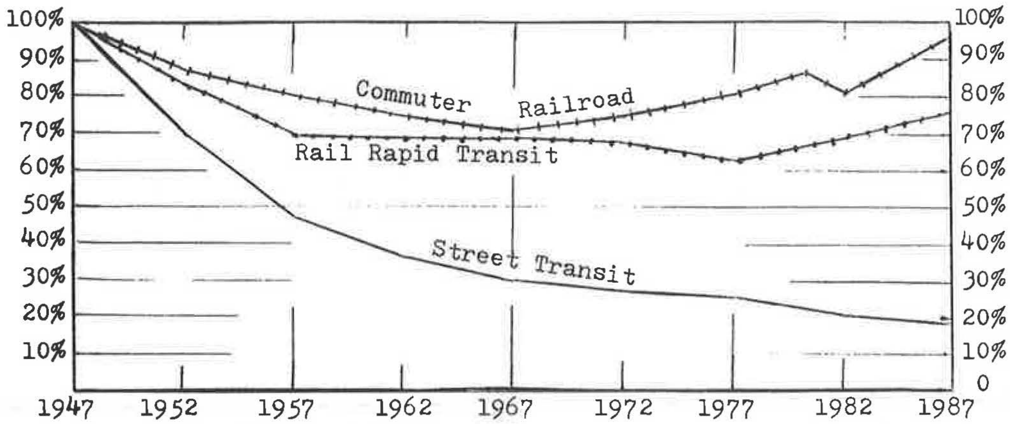
Arlington County Department of Public Works, 1400 Court House Rd., Room 221, Arlington, Va. 22201.

TABLE 1 CHANGE IN TRANSIT TRAVEL, 1945–1975

	Rapid Transit		Light Rail		Commuter Rail		Urban Bus		Suburban Bus		Total	
Year	Amount	Change (%)	Amount	Change (%)	Amount	Change (%)	Amount	Change (%)	Amount	Change (%)	Amount	Change (%)
Millions of Vehicle Miles in Service												
1945	458.4	–	939.8	–	222	–	1,855.6	–	(153)		3,475.8	
1955	382.8	−16	178.3	−81	184	+2	1,886.4	−7	(142)	−7	2,631.5	−24
1965	395.3	+3	41.6	−77	159	−14	1,571.3	−17	(124)	−13	2,191.1	−17
1975	423.1	+7	23.8	−43	161	+1	1,541.3	−2	67	−46	2,216.2	+1
Millions of Passengers Carried												
1945	2,698	–	9,426	–	323	–	11,130	–	(895)	–	23,577	
1955	1,870	−31	1,207	−87	258	−20	8,452	−24	(534)	−40	11,787	−50
1965	1,858	−1	276	−77	228	−12	6,119	−28	(334)	−37	8,510	−28
1975	1,683	−9	124	−55	260	+14	5,162	−16	161	−52	7,390	−13
Passengers Lost (in Addition to Service Cuts)												
1955		−15		−6		−22		−17		−33		−26
1965		−4		0		−2		−11		−24		−11
1975		−16		−12		+13		−14		−6		−14
Over 30 years		8 (cut) 38 (loss)		97 (cut) 99 (loss)		27 (cut) 20 (loss)		17 (cut) 54 (loss)		56 (cut) 82 (loss)		36 (cut) 69 (loss)
Net		30 (loss)		2 (loss)		+7 (gain)		37 (loss)		26 (loss)		33 (loss)

Light Rail Plus Urban Bus

Year	Millions of Vehicle Miles in Service	Millions of Passengers
1945	2,795.4	20,556
1975	1,565.1	5,286
Cuts/losses Amount	1,230.3	15,270
%	44	74



SOURCE: APTA Fact Books

FIGURE 1 Trend of transit ridership, 1947–1987.

not uniformly segregate commuter from intercity requirements, as they now do.)

Passenger-miles traveled on shrinking commuter railroad systems declined 7 percent, from 5.6 billion in 1945 to 5.2 billion in 1975. During this same period, suburban bus systems lost 82 percent of their patronage, dropping from 895 million passengers in 1945 to an estimated 161 million in 1975. This loss was despite rapid growth in suburban population and bus service offered, as well as the abandonment of 7 of the 21 commuter rail systems (*8*).

Metropolitan bus services inherited many of the transit riders left by the receding electric railways, but the number of buses in service declined from 53,381 in 1945 to 51,514 in 1975. In Table 1 and Figure 1, these trends are analyzed in 5-year increments to determine their characteristics. During this 30-year period, transit patronage fell 69 percent, forcing a 38 percent reduction in service. The decline in patronage was 31 percent greater than the curtailment of service, sharply reducing transit productivity in inflationary times—the worst of both worlds.

The various transit modes had different responses within the general trend. Light rail (or street car) service lost 98.7

TABLE 2 CHANGES IN TRANSIT SYSTEM USAGE, 1950–1980

1980 Population	Area	Change (%)	Current Passengers	Change (%)	Current Vehicles	Change (%)	WW II Rail (%)	Current Rail (%)	Old Habit	New Habit	Change (%)	Comments
6.78	Chicago	+25	484.9	−56	4,808	−21	90	65	261	72	−72	
3.81	Detroit	+14	52.0	−88	976	−66	41	0	208	14	−93	All bus
3.00	Toronto	+173	450.0	+46	2,609	+100	80	51	280	150	−46	50% rail
2.68	Washington	+144	123.0	−67	2,050	−1	45	0	301	46	−85	All bus
2.76	Washington	+151	250.0	−32	2,284	+11	45	55	301	91	−70	50% rail
1.85	Saint Louis	+15	37.7	−85	773	−52	58	0	155	20	−87	All bus
1.81	Pittsburgh	+2	68.8	−69	1,064	−26	82	6	155	38	−75	Some LRT
1.75	Cleveland	+19	75.7	−69	828	−42	76	20	191	34	−82	
1.61	Atlanta I	+92	76.4	+12	900	+102	78	0	122	47	−61	All bus
1.61	Atlanta II	+92	100.9	+47	990	+122	78	51	122	63	−48	New rail
1.56	Dallas	+188	28.6	−69	723	+50	58	0	169	18	−89	All bus
0.72	Ottawa	+241	78.4	+185	793	+372	83	0	126	109	−13	All bus
0.67	Oklahoma C.	+168	3.8	−93	95	−55	34	0	175	6	−97	All bus
Summary of 26 areas												
Median > 50% rail		+73	236.0	−44	2,446	−5	76	59	229	63	−71	
Median 40–49% rail		+95	218.2	−41	3,339	+37	63	41	193	62	−68	Two cases
Median 6–25% rail		+27	47.2	−70	697	−30	61	18	166	34	−80	
No rail remaining		+109	34.0	−75	748	−11	65	0	164	21	−87	

NOTES: Population and annual ridership in millions. Percentage of rail service is based on percentage of passenger-miles travelled. Sources: UMTA Section 15 Reports, *Mass Transportation Directory*, Kenfield-Davis, Chicago.

percent of its passengers, primarily because of the 97.5 percent reduction in service when buses were substituted for rail cars. From a reciprocal point of view, 2.5 percent of the rail service remained, carrying 1.3 percent of the passengers, a loss of 48 percent over 30 years. Bus service, which inherited most of the rail ridership, lost 54 percent of its 1945 riders, despite the rail riders added to bus over that period. Considering that new buses on improved highways often replaced worn-out street cars on bad track, the overall result is disconcerting and may help to focus on the transit's loss of market share.

In contrast to these bus rider losses (75 percent, if street car and bus passengers are grouped together), rail rapid transit lost only 30 percent of its riders during the same period. Nearly half of these were lost around 1952, when the financial community stopped Saturday work. (Saturday had been the highest ridership day of the week.) Commuter rail lost only 20 percent despite the loss of one third of its lines and the loss of much Saturday travel. It lost only 7 percent of its passenger-miles as the suburbs grew farther out and a lower-income population filled the inner suburbs.

These data are much too generalized to allow anyone to draw sound conclusions, but they do suggest that bus transit may not be able to hold or sustain the same market share as rail transit, if other factors are equal or similar. Few would suggest that service in which a new motor coach replaces a worn-out street car would cost more, run less frequently, or be slower. A more case-specific study of this phenomenon may be required because it appears that there is a difference in ridership (Table 2).

CASE HISTORIES

Bus and Oil Affiliates

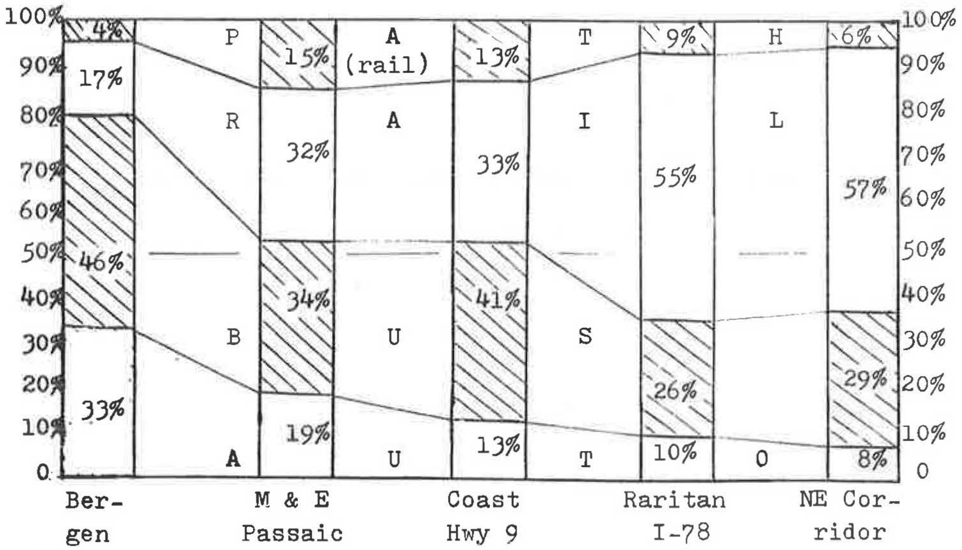
Transit systems in Baltimore, Chicago's North Shore suburbs, Kansas City, Los Angeles, Milwaukee's suburbs, the Twin Cities (Minneapolis-St. Paul), New Jersey, Oklahoma City, Philadelphia, and St. Louis were all affiliated with bus manufacturing or oil marketing companies for the specific purpose of replacing rail service with buses. In 1948 these properties operated 7,574 rail cars and 7,142 buses serving 1.9 billion revenue passengers per year. By 1986, these figures had declined to 1,700 rail cars and 11,875 buses serving only 793 million revenue passengers (estimated from unlinked trips and passenger revenue), a decline of 60 percent. Productivity per vehicle declined 55 percent. If the huge population growth in Los Angeles is excluded, the other systems declined 68 percent in revenue passengers.

In Baltimore, a 5-cent fare was promised when the new management began to replace the rail cars with buses, but instead fares increased, just as they did elsewhere. In the North Shore suburbs of Chicago, commuters fought to save their rail lines and opposed the use of buses. When the trains stopped, no buses took their place.

In Kansas City, the president of the Association of Commerce warned that the conversion of the important Country Club rail line would harm downtown business, and indeed it did. Later, Seymour Kashin, Assistant General Manager of the Transit Authority, reported that the Troost Avenue rail line, extended in 1946, carried more passengers than the entire bus system now does.

In Los Angeles, the last interurban rail line carried 5.2 million annual passengers in 1961 before it was replaced by a Freeway Flyer and a local service bus line. These bus lines carried 4.1 million passengers the first year, down 21 percent, and only 3.8 million passengers in the second year, down 26 percent, despite the more frequent service. This rail line is now being restored and is expected to carry 10 to 12 million passengers annually. The population growth in the area accounts for some of the expected increase.

In Minneapolis-St. Paul, the top managers involved in the rail-to-bus conversion were sent to prison as ridership fell. New Jersey suffered one of the sharpest declines in annual rides per capita—except for its one remaining light rail line, which has lost no significant number of passengers over the



SOURCE: S.Jurow, NJT, TRB, 1987

FIGURE 2 **Submodal split across the Hudson River, New Jersey.**

past 35 years, despite the sharp population decline in Newark where it operates. In Bergen County, New Jersey, which has an exclusive busway into New York City, transit has a lower modal split than in any other part of the commuting area. The split is even lower there than it is where the commuter rail lines end at the New Jersey waterfront, requiring a transfer at $1 to cross the river (Figure 2).

In the western Milwaukee suburbs, when new buses replaced the old rapid transit rail line in 1951, ridership dropped 54 percent over a 2-yr span. Bus running time was 10 minutes longer than rail at that time, suggesting a loss of 21–22 percent of the riders. The balance of the loss, however, must be attributed to the mode (*9*). At the Waukesha rapid transit station, when buses were loading at the rail platform ahead of the rail car or train, only 26 percent of the passengers chose the bus, despite the 20 percent lower fare. It is probable that the lower fare offset the longer time, leaving the low modal share to passenger preference (*10*).

After rail service was eliminated in Oklahoma City and its environs, transit use fell 97 percent on a per capita basis. In St. Louis, with all-bus service, only 13 percent of the riding habit remains. St. Louis has now contracted to restore rail transit on a Metrolink from the airport through downtown to East St. Louis to recover some of the transit market share.

At one time, St. Louis was a leader in the transit industry. In their 1959 Annual Report, St. Louis Public Service Co. management wrote that

> our company proposes to acquire the usable assets of certain other suburban bus operations and to purchase 125 additional luxury buses, 75 for street car conversion and 50 for revitalization of the county system. We would air-condition another 100 buses in our present fleet.

The report quoted the company's consultant:

> St. Louis Public Service has made an outstanding contribution to the industry and to the St. Louis area by trying out new methods of attempting to attract patronage. At the present time, the St. Louis area is enjoying the largest fleet of air-conditioned buses in the country. The Company has experimented with shorter headways in an effort to attract patronage. These and other promotions place this Company very high on the list of progressive operating managements.

Despite these comments, patronage was down 44 percent from 1947 as the rail service was cut back in favor of buses on freeways. The company sold its remaining rail cars to San Francisco, where ridership has held up more effectively. By 1986, transit in St. Louis was at a very low ebb (*11*). The losses would be even greater if the interstate electric railway had been included in the data.

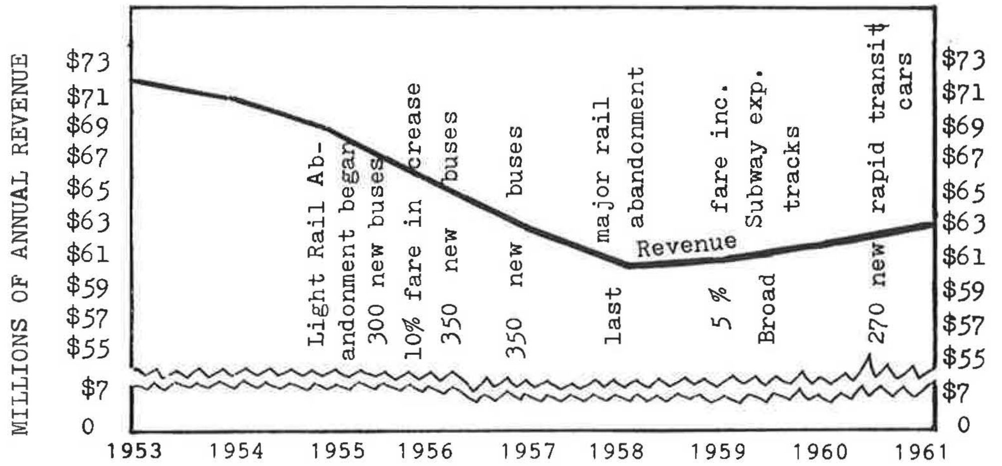
In Philadelphia, which has trunk subway lines, bus substitution was limited to surface rail lines, and even these retain some rail operation. One rail-to-bus substitution was conducted as a trial. Ridership on route 42 dropped off markedly, and now, with an exclusive busway in Center City, it is only 33 percent of rail volume. During the trial, the Schuylkill River bridge was rebuilt without tracks, so rail service could not be restored even though the test was a failure (*12*). This was not a failure of coordination, but a highway engineer's strategy, abetted by the new owners of the transit system.

Between 1954 and 1956, the new management of the Philadelphia Transit Company purchased 1,000 new diesel buses to replace some old gasoline buses and many rail cars. During the installation of these new buses, passenger revenue fell 14 percent, as shown in Figure 3. Overall, from 1948 to 1988, transit travel in Philadelphia declined 63 percent, with most of the decline during the conversion from rail to bus.

Holding Company Dissolution Act

Transit systems in Atlanta, Milwaukee, Portland (Oregon), Pittsburgh, Tampa, and Washington were part of utility companies that also sold electric power. They were ordered by the federal government to dispose of either their electric power or transit business. It was deemed illegal for a utility company to provide both power and electric transit services.

During the Great Depression, it was not possible for the



SOURCE: Philadelphia Transportation Co.

FIGURE 3 Philadelphia ridership with 1,000 new buses.

companies to sell their transit properties. Milwaukee spun its transit system off from the power part of the business by sending new shares of stock to the stockholders, but the other systems waited until profits from World War II gasoline rationing put enough cash in transit coffers to attract buyers. In Atlanta, as the system was converted to bus, ridership fell despite excellent management, but plans were begun for rail rapid transit (Atlanta will be reviewed further in the bus-to-rail portion of this analysis).

Milwaukee

In Milwaukee, a consultant found that the substitution of buses for rail service increased ridership 100 percent from 1938 to 1943. Public review of the report cited gasoline rationing as the prime reason for this great increase, and a comparison with Pittsburgh disclosed that ridership gained even more there, with no rail-to-bus substitutions (*13*). A consultant suggested that the Wells Street line might be studied for rail modernization, but the study was never made, despite the large amount of new rail installed in 1950. Ridership in Milwaukee is now 70 percent below its post-WWII peak.

Portland

In Portland, as post-WWII conversion of rail lines to bus accelerated, ridership dropped 14 percent per year—one of the sharpest declines in the nation. The exception was ridership on the suburban rail lines before conversion. After the less-severe decline that occurred when Saturday was phased out as a workday, ridership began to grow again, paralleling the experience in Shaker Heights, Ohio. Then the highway department closed the bridge into downtown for repairs, truncating rail service short of downtown and requiring a shuttle bus to complete the trip. This depressed ridership severely (although not as severely as Portland's bus ridership) until a 33 percent fare increase was applied. Service was then discontinued in defiance of the Public Utility Commission. An appeal to the court was fruitless because the highway department had rebuilt the bridge without rails. Bus ridership continued its sharp decline, and by 1958, ridership was down 74 percent (*14*).

Pittsburgh

The Pittsburgh transit system was captured by stock speculators when the utility company had to sell. The speculators disbursed the modernization fund as dividends and left management to operate as best they could. Ridership did not begin to decline until a 20 percent fare increase in 1948, but an annual series of strikes in the 1950s rapidly dissipated ridership. A public authority condemned the property in 1963 and began a rapid rail abandonment program. With public subsidies, no further service curtailments were made, and ridership stabilized at 69 percent below the Great Depression level.

In recent years, two new exclusive busways have been built to speed bus travel. The South Busway opened first, parallel to one of the remaining rail lines. Ridership grew slightly during the 1980–1981 energy crisis, but by 1984, it had fallen off to a level lower than before the busway opened. The second busway, to the east, was completed in 1983. It provided a new EBA bus line, making ridership comparisons difficult, but the system load factor declined from 12 to 10.5 passenger-miles per bus mile despite the use of articulated buses on EBA. The promise of 80,000 passengers per weekday never materialized. Ridership is between 21,000 and 29,000 each weekday in the most densely populated area of the city and its suburbs (*15*).

Two rail corridors were retained in Pittsburgh, with a plan to convert one of them into an automated guideway, but opposition blocked this federally funded effort. The two rail lines continued to operate, with patronage increasing from 20,000 per weekday after World War II to 24,000 by the time that the rail system was disrupted for reconstruction. This trend was diametrically opposed to the rest of the system. An alternatives analysis determined that light rail service should be provided. A new downtown subway replaced street operation. Ridership increased to nearly 30,000 each weekday, with little change in travel time. Data compiled by Southwestern Pennsylvania Regional Planning Commission reveal that rail ridership 10 miles from downtown is at the rate of

39 annual rides per capita. Bus travel is at the rate of 10 in the South Hills and 19 in the north, where there is no rail service. The rail rate is the same as in the Philadelphia area.

Tampa

The Tampa Electric Company operated 100 rail cars in that city until the Tampa Utility Board refused to allow the transit property in the rate base, forcing it out of business. National City Lines, which also operated 37 buses in Tampa, took over the entire operation after the rail system's demise. Despite rapid population growth, ridership has fallen 60 percent with an all-bus system. Per capita ridership has fallen 81 percent (*16*).

Washington

The Capital Transit Company in Washington was forced to sell to scrap dealer Louis Wolfson after wartime profits made the sale attractive. Because of the order to sell, the company had not been willing to make the heavy rail investment that was essential to relieving congestion of its cars in front of the White House. Accordingly, it sought to replace Benning number 10–12 line rail cars with buses on different streets to relieve rail congestion. Public protests were overcome, and the change was made. Ridership began a 25-yr decline, forcing Wolfson to severely truncate Maryland service to keep solvent. This so angered the public that Congress revoked the franchise during a 2-month strike, forever banning rail cars from the city streets.

For a time, no responsible new operator could be found, but eventually the owner of Trans-Caribbean Airlines came forward with $600,000 down and the promise to pay $2.5 million cash in two weeks, as well as assuming the outstanding debt. He used the company's own cash to buy the system. This buyer then sought relief from the rail abandonment order, but to no avail. In 1963, rail service was terminated, and ridership continued to decline until the low point in 1973, 67 percent below 1948 levels, despite the opening of the Shirley busway to suburban Virginia. In 1976, rapid rail transit came to the area, and ridership has doubled, as will be reviewed further along in this analysis.

Political Interference

Several rail transit systems were forced out of business by overpowering political pressure.

Chicago

In Chicago, a public authority took over the nation's largest street railway in 1947 and immediately began to cut back on rapid transit branch lines and eliminate all street railway lines, despite the presence of 600 brand-new cars. Fares escalated as fast as ridership declined. From 1948 to 1970, the decline was 63 percent. During the same period, rail rapid transit ridership increased 7 percent (*17*).

A comparison of 1960 data with 1970 data reveals a decline of 30 percent on the new city bus system, a suburban bus decline of 36 percent, a rapid transit decline of 6 percent, and a satellite bus decline of 71 percent. Commuter rail ridership increased 7 percent (*18*). In Chicago's western suburbs, the Chicago, Aurora & Elgin Railway was forced to eliminate its direct service into Chicago's Loop so that construction of I-90 would be simplified. Commuters were required to transfer in Forest Park to the Chicago elevated railway on street trackage through the construction zone. Suburban ridership dropped 50 percent, half due to the forced transfer and one fourth each due to slower trip time and higher fares. Without the higher through trip revenue, the railway could not cover its expenses, and it had to shut down in 1957.

Leyden Motor Coach moved in to provide the service but was unable to attract sufficient patronage to support a bus line. In 5 yr, ridership of 7 million annually was completely eliminated (*19*).

Montreal

The Montreal Tramways Company, the largest transit system in Canada, was taken over by the city for the express purpose of eliminating the company's 994 rail cars. The resultant loss of ridership and profitability reduced Montreal to the second largest transit system in Canada, but ridership did not fall as sharply as it did in the United States under similar conditions. In 1967, a new subway system was opened and attracted high ridership, but not as high as that of Toronto's more rail-oriented system. Annual per capita transit revenue is $63 (Canadian dollars) in Montreal, and $116 in Toronto, where fares cover 68 percent of operating costs. In Montreal, the coverage is only 46 percent. The transit modal split downtown is 55 percent in Montreal and 70 percent in Toronto, with 54 percent of the passengers on rail cars. Montreal is 59 percent bus. Ridership in Toronto continues to increase (*20*).

Cincinnati

After World War II, the Cincinnati Street Railway modernized its system with new rail cars and infrastructure, as directed by the city. The next City Council reversed the policy by ordering removal of all rail service (*21*). The financial losses from the abandonment of nearly new rail facilities forced frequent fare increases on the riders, until it became the first major city to have a 55-cent fare. The ridership decreased 88 percent during 40 yr.

Detroit

Detroit had eliminated all electric railway service by 1956, along with much of the ridership. The General Manager's report in 1957 promised that "This was certainly a major step in the program of rehabilitating Detroit's transit system, making it possible to continue making improvements in transit service by expanding express operations via Detroit's growing expressway [freeway] system."

The rail cars that were replaced were relatively new, fast, and profitable, with fares covering 148 percent of operating expense. Bus revenues at the time were only 107 percent of operating expense and declining. The ratio is now only 30 percent, despite one of the nation's first $1.00 base fares. Ridership has declined 88 percent since 1947 (*22*). With the loss of its transit riders, the city has lost its last major downtown department store. Recently, a new elevated rail loop has been built downtown, but it provides little home-to-work service. It was built to connect with a light rail line that has not been funded.

Dallas

The Dallas Railway & Terminal Company began a rail modernization program after World War II, when ridership was 91 million (in 1948). The company was forced to agree to eliminate all rail lines as a condition of approval for a needed fare increase. With only two major rail lines remaining in 1954, ridership was down to 73.5 million. By 1957, all rail lines were gone, along with 52 percent of the system's ridership in a growing area (*23*). By 1981, revenue passengers (linked trips) were down to 29 million, an overall loss of 59 percent. The decline in riding habit was 89 percent.

Buffalo

In Buffalo, a similar agreement between the transit company and the city mandated the elimination of rail service, which was not modern. The company boasted that "Buffalo leads all cities of a half million or more in progress toward complete bus substitution. Nearly 70 percent of all IRC passengers are served by bus." Apparently, the bus service was not very good. Ridership began to decline in 1944, before the end of gasoline rationing, just as happened in Detroit. When war restrictions on fuel were lifted, all rail service was abandoned, and the company soon went bankrupt.

It was reorganized as the Niagara Frontier Transit Co. and was ably managed by Roswell Thoma for several years, but the decline in ridership slowed only briefly. By the time that light rail transit was restored to Main Street, system ridership had declined 82 percent from the 1944 peak (*24*). In fairness, however, it must be noted that key employers were lost to the city during this period, causing a marked decline in population.

Eastern Pennsylvania

Rail service to Reading, Pottstown, and Pottsville, Pennsylvania, was ordered to shut down by the state Department of Transportation in 1980, in outright violation of the Public Utility Law. Capitol Bus Company (Trailways) was then operating five round trips, in direct competition with seven rail round trips out of Philadelphia. Bus and rail combined served 1,800 weekday passengers at that time. The bus service was expanded 40 percent to cover loss of the trains, but there was no need to do so. Only 200 weekday bus passengers remain on the route, a loss of 89 percent over three years. The local buses are 20 minutes slower than the trains, and express buses bypass local stations. Considerable loss therefore might be expected, but nothing like 89 percent. This severe loss parallels an earlier loss in the nearby Allentown corridor.

Company Policy

Eastern Pennsylvania

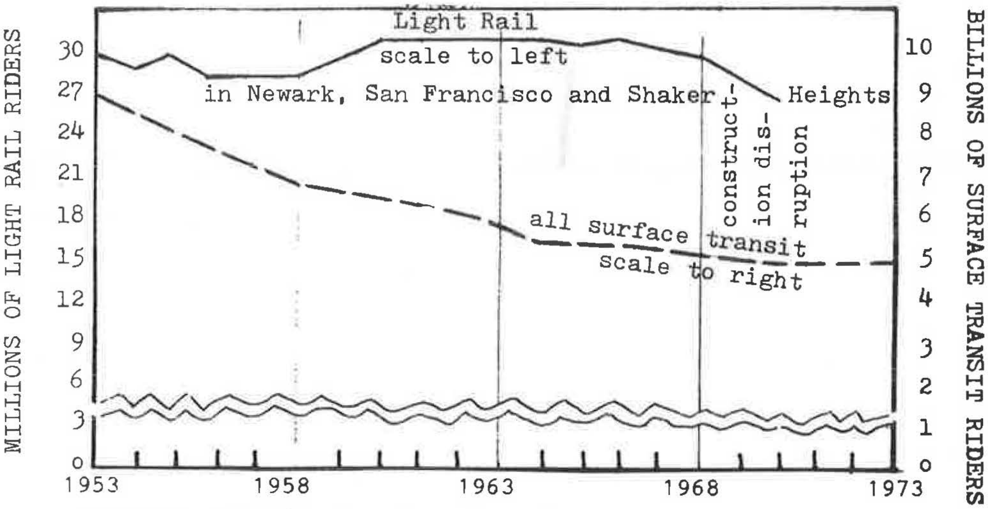
In 1951, Lehigh Valley Transit Co. abandoned its hourly electric railway service between Allentown and Philadelphia's western suburbs. It continued its motorbus pool service in coordination with Reading Transportation Co., providing eight round trips between Allentown and downtown Philadelphia. Reading Railway also provided six round trip trains that made local stops. The electric railway was the only one serving Norristown en route, but at a time penalty, plus a transfer to reach the center of the city. No meaningful bus service replaced the hourly rail service. Extra sections were added to any existing bus trips that required them—but few did. Rail passengers just disappeared. Total travel by transit in the corridor declined from 1,600 per weekday with two rail lines and one bus line to 1,000 without the electric railway, then down to 240 after the state Department of Transportation ordered discontinuance of all rail service. This is an overall decline of 87 percent (*25*).

West of Philadelphia, one of the last privately owned transit companies, the Philadelphia Suburban Transportation Company, operated suburban rail and bus service at profit. Two of their rail lines had been converted to bus in 1954. Both were single track. One was on the side of a state highway for 18 mi, and the other was near the main line of the Pennsylvania Railroad, which provided direct service to Philadelphia. As of 1954, the Company had lost no passengers (net) to the growing "automania," but the state highway department and the federal income tax provided strong incentives for the company to divest itself of its rail transit lines. The highway department wanted to use the longer line for land on which to widen its highway, which had once been a company-owned toll road.

The transit company planned new air-conditioned buses on the improved highway. Rail cars had to run in trains at peak hours to cope with the single track, so smaller buses could offer more frequent service. Very slight ridership gains resulted from this bus substitution, but only at first. The improved highway and suburban growth attracted too much automobile traffic, congesting bus movement. In an attempt to retain riders, buses were extended into Philadelphia to avoid the subway transfer at 69th Street, but riders did not prefer the "one ride." The service was withdrawn after a 2-year effort.

The other 4-mile line was a branch of the Norristown High Speed Line (Philadelphia and Western Railway), which provided local service every 20 minutes in coordination with express service to Norristown. The Norristown line got the 20-minute local service, except in rush hours. The Strafford branch was sold to the highway department for a US-30 bypass, against the company attorney's advice. An abutting property owner discovered his family's reversionary easement and took possession, so the transit company had to refund the sale price. At the same time, the bus substitution was not holding ridership: many bus trips ran nearly empty. Service had to be cut back, losing more riders. Eventually, only three rush-hour trips were left, and now these are gone. The story closely parallels the Chicago suburban experience.

In 1967, the company tried again, abandoning its Ardmore rail line on a median in Highway 3 and on private right-of-way, a total of 5 mi. Not a single favorable public witness appeared at extended public hearings, other than company



SOURCES: Moody's Investors Manual - Transportation
San Francisco Municipal Railway

FIGURE 4 Trend of light rail versus bus ridership.

officials, but the Public Utilities Commission determined that only the company was competent to determine the matter (*26*). It had been shown that buses did not have the capacity of rail cars and that traffic congestion would impede buses, adding to bus costs and degrading service quality. The company countered with an offer to build America's first exclusive busway. It did. Again, a portion of the property was sold to the highway department, and crossing gates were provided for the busway. The rail line had none.

The opponents of this change were prophetic. Ridership fell 15 percent with the busway, despite more costly service. The crossing gates did not work well with rubber-tired vehicles. Neighborhood youths found the busway a good drag strip. No one benefitted except the company, which received an income tax refund for its rail abandonment and its sale of the entire system to a public authority for nearly twice its appraised value.

In 1956, John McCain, president of the company, promised to eliminate all rail operation before he retired. Since then, two remaining light rail lines have been improved with new cars, and the Norristown line is now having its 55- to 63-year-old cars replaced. Bus ridership keeps evaporating.

Cleveland

The city of Cleveland bought its transit system in 1942 and undertook a bus substitution program after World War II. By 1948, ridership was falling 14 percent per year, while ridership in neighboring Pittsburgh, with a similar economy, remained stable (*27*).

Cleveland's two independent light rail lines did not fare similarly. Cleveland undertook to build its own rail transit line, sharing the downtown portion of the light rail right-of-way. The system opened to travel in 1956 and extended westward until it reached the airport a few years later (see Figure 4).

At the same time, Cleveland replaced its city-owned street railways with buses, many express, for which the general manager was recognized nationally by the Urban Land Institute. Despite the improved bus service, the decline in patronage did not stop. By 1986, the Greater Cleveland Regional Transit Authority, excluding the two light rail lines, had lost 72 percent of its riders since 1948. The two unchanged light rail lines had lost only 25 percent, despite the loss of the Saturday business day and despite the distant competition of the newer city rapid transit line, which has fared badly after an auspicious start.

UPTREND

Ottawa, Canada

Not all transit systems have suffered as greatly as those described. The most successful bus system on the continent is the OC Transpo in Ottawa, Canada, the nation's capital. By restricting free automobile parking, by practicing high-minded zoning controls, and by offering user-side subsidies to bus riders, OC Transpo has developed the highest all-bus riding habit on the continent. Aided by a population increase of 400 percent, transit ridership has increased 241 percent. This represents a loss of market share but is by far the best results of any major bus system.

To assist in coping with rapid growth and to update the transit system, Ottawa has built an expanding exclusive busway at a cost of several hundred million Canadian dollars. This project has not had the desired effect. Ridership that had been growing because of the transit incentives has begun to decline as the busway was phased in. Ridership is down about 25 percent, and rush hour local fares are up to $1.60 (ridership data at this fare are not yet available) (*28*).

Atlanta

The loss of ridership in Atlanta has been described, but the introduction of rail rapid transit service has changed that situation. Atlanta now has two rapid transit lines, one extending north from the airport through Five Points (the CBD) to the northern suburbs, and the other extending west from east of Decatur to Hightower Road, a mile short of Atlanta's beltway, I-285. Markedly reduced fares have escalated back to typical rates, and ridership has grown with rail extensions. It is now 32 percent higher than it was 40 years ago, when nationwide ridership was at its peak, and has grown approximately 150 percent from the all-bus low in 1971. The reduced travel time made possible by rapid transit accounts for less than 50 percent of this growth. Rail rapid transit accounts for growth of more than 100 percent, a figure similar to the growth in the Lindenwold, N. J., corridor (discussed later).

Boston

Boston converted all of its local street railways to bus operation a generation ago, but the backbone of its service is a system of rail lines, including commuter, light rail, and rapid transit. As the number of rail cars was cut in half, ridership fell 66 percent over 40 years. The electric rail lines did not extend very far into the suburbs until recent years.

In contrast to this general trend, light rail transit was extended through the suburbs of Brookline and Newton to belt highway 128 in 1959. Originally a steam railroad, this system carried 3,140 passengers before it was converted to light rail. During the conversion, Middlesex and Boston buses attracted approximately 2,500 weekday riders with all-day service, a figure 20 percent less than the ridership for railroad's primarily rush hour service.

After light rail service began, 26,000 weekday passengers appeared. This 940 percent increase over shuttle bus volume and 728 percent increase over direct desultory railroad service threw schedules into disarray. Faster travel time and subway distribution in the hub accounted for a healthy portion of the increase, but rail transit was the primary attraction in this high-income, automobile-dominated area (*29*).

Toronto

Toronto is one of the very few cities to enjoy more transit riders in 1988 than in 1948. The urban area has grown markedly, but the city of Toronto has not. Absolute ridership has grown 46 percent during the past 40 years while other systems declined. The number of rail cars has increased with time and now exceeds 1,000. Streetcars continue to serve where subways have not replaced them. More than 50 percent of the area's transit work is done by rail. Since 1967, a new regional (commuter) rail system has been added, and new rail lines are being added as ridership continues to grow (*30*).

San Francisco

At the end of World War II, National City Lines acquired the Key System transit lines on San Francisco's East Bay and eliminated all electric transit operation. Ridership fell faster and farther than in any other major area, despite the express buses that replaced transbay rail service. In the city of San Francisco itself, the Municipal Railway held its patronage better than did rail systems in most other cities. It retained electric transit operation, including streetcars on Market Street.

The people of the East Bay created a new transit district in an attempt to reverse their transit decline. A great improvement was made with public funds, but the modal split remained low. The citizens of the larger region then decided, by ballot, to restore rail transit to the East Bay and west to Daly City, with a new tunnel under the bay. The Bay Area Rapid Transit District began restored rail service in 1972. By 1975 "some 44 percent of BART patrons came from buses, over 20 percent was added to the number of daily trips in the . . . Bay area, and total non-BART trips by transit also increased" (*31*). Since 1975, BART travel has increased markedly, reaching a total of 210,000 weekday passengers. Travel on the light rail lines in San Francisco, partially parallel to BART, has increased 50 percent at the same time. In recognition of this trend, the area has funded seven rail extensions.

New Jersey

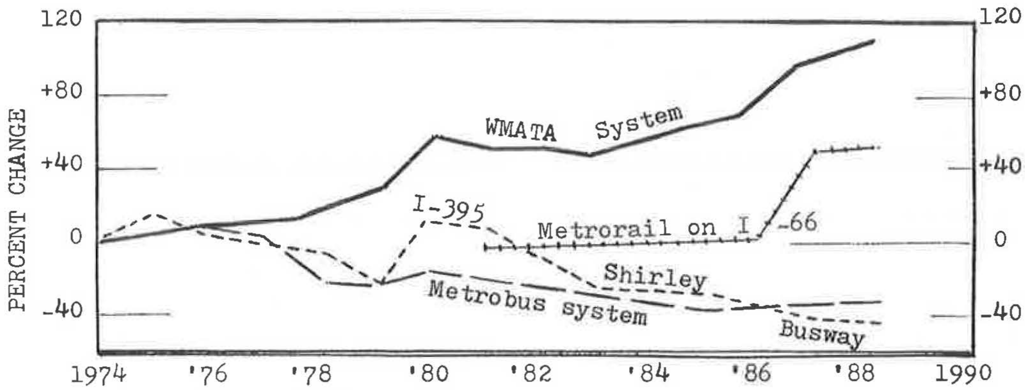
Northern New Jersey was once connected to New York City by ferry boats, two subways, and a railroad. When the highway tunnels and bridges were opened to automobile and bus travel (1926–1936), some rail travel was diverted, particularly in the off-peak periods. New Jersey then had the highest railroad taxes in the nation, which, with the Great Depression, forced a cutback of unsubsidized rail service. Several lines were totally discontinued, but bus ridership also declined. To improve bus service, the Port Authority of New Jersey and New York set aside an exclusive counterflow lane in the Lincoln tunnel with a 100-bay bus terminal in Times Square. Commuters have not been pleased with the congested operation.

Bergen County, New Jersey, with a million people, is across the Hudson River from the Bronx, New York. Many residents commute to Manhattan. One third pay high tolls and parking fees to drive in. Only 21 percent can use rail service because most of it has been eliminated. Buses serve 46 percent.

Essex, Morris, and Passaic counties in New Jersey still have much of their rail service. It does not cross the river, however, and the connecting ferries have been eliminated. Each rail commuter must pay an additional $2 per round trip to cross the river on a crowded subway or on a bus. Despite this, 47 percent of the travel is by rail and 34 percent is by direct bus, leaving only 19 percent to automobile travel. The bus share dropped 26 percent as more rail service became available, and the automobile share dropped 42 percent (Figure 2).

From the North Jersey Coast, with some direct rail service, the rail share is 46 percent, and buses on the New Jersey Turnpike attract 41 percent. The automobile captures only 13 percent. From Union and Somerset counties (in the same rail corridor but without direct rail service), 64 percent of the commuters chose rail, 26 percent bus, and 10 percent automobile. On the spine of the Northeast Corridor, with all-direct train service to Manhattan, 63 percent of the commuters chose rail, 29 percent Turnpike buses, and 8 percent automobiles (*32*). It appears that the larger the share of bus travel becomes, the larger the share of automobile travel as well. Rail use in this area has increased 40 percent since 1983, suggesting higher rail shares than reported here.

In southern New Jersey, Port Authority Transit has con-



SOURCE: Metro Washington Council of Governments and WMATA

FIGURE 5 Transit trends in the Washington, D.C., area.

nected Lindenwold, New Jersey, with Philadelphia by rapid rail transit since 1969. Bus ridership in the ara had been declining for years as the suburban population grew. With rail service added, ridership increased 115 percent. Bus service was continued but has gradually been reduced for lack of passengers. The PATCO rail line covered all operating and maintenance costs from fares at first, but the inflationary spiral has reduced the revenue-to-cost ratio to 74 percent in 1987. The bus ratio in this area is about half that figure.

Washington

In 1973, the Washington Metropolitan Area Transit Authority began serving the area's 123 million annual bus riders. In 1988, with more than half of the patronage back on rails, ridership had grown to 250 million, up 103 percent. Revenue is up 320 percent on fare increases of 67 percent. Rail passenger-miles exceed bus passenger-miles by 30 percent (transfer passengers not included).

About the time of the opening of the Lindenwold, New Jersey, line, the Shirley Busway opened on I-395, south out of Washington, for the same purpose over a similar distance. It was an immediate success. The Springfield, Virginia, area supported only three bus round trips per weekday before the busway. Now Springfield has service every few minutes in rush hour, with hourly service midday. Although the population of this region is similar to that of the Lindenwold line corridor, ridership is not. The riding habit in the Springfield area is 17 annual rides per capita, adjusted to 8.5 mi from the city center. The Lindenwold habit is 55. Ridership on the busway has declined 42 percent since the 1980 energy crisis as fares have increased and as car pools have been allowed on the busway (Figure 5).

In 1986, Metrorail opened an 11-mi line from Rosslyn to Vienna, Virginia, serving a corridor similar to the Shirley Busway but on I-66. With 2 years of travel development, Metrorail has attracted a riding habit of 51 (adjusted to 8.5 miles out), which is triple the bus rate. Rail running time is 22 minutes with 7 stations, whereas busway time is 20 minutes without stops.

Prerail express bus service in the I-66 corridor could not support any off-peak express service. The trains attract 500 passengers per hour from the outer stations. Local buses continue to parallel the rail line without much change. The rail revenue-to-cost ratio increased to 75 percent with the extension, with no change in fares. The bus revenue-to-cost ratio in Fairfax County was 24 percent before rail operation (*33*).

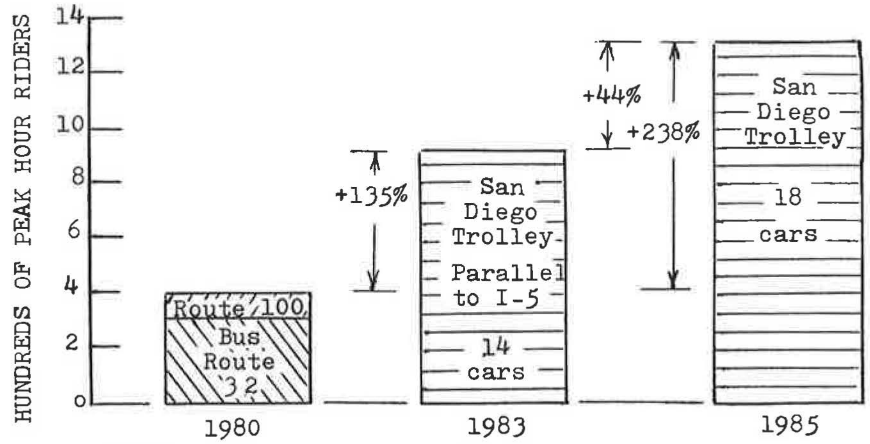
San Diego

San Diego resumed rail transit service in 1981 with a 16-mi line parallel to Bus Route 32, the area's busiest. The city had lost ridership rapidly when the original street railway was converted to bus after World War II. Despite rapid population growth and a stabilized bus system, ridership had fallen 53 percent before rail transit was resumed in 1981.

The Route 32 and Route 100 buses in the South Bay corridor served 12,000 weekday passengers. With rail service, Route 32 was truncated short of center city, and Bus Route 100 on I-5 was discontinued. The 15-min headways were unchanged during the period, but rail running time is only 40 min, compared with 75 min by bus. Initially, ridership was unchanged: 10,000 on the trains and 2,500 remaining on Bus Route 32. Rail ridership has been growing ever since, however, with 26,000 weekday passengers in 1988. A second short rail line has been added, bringing rail ridership to 29,500. The single-line increase was 160 percent in 7 yr, even though rail fares are higher than bus fares (except in center city). In the peak hour, at the maximum load point, ridership has increased 238 percent (Figure 6). Travel time savings could account for an increase of 92 percent. The balance of the increase may be attributable to rail service. The rail revenue-to-cost ratio is the best in the industry, and the cost per passenger-mile is the lowest (*34*).

Buffalo

When Buffalo's light rail line was completed, it attracted 30,000 school-day riders in the Main Street corridor. This is an 82 percent increase over previous bus service, some of which still operates. Faster travel time may account for 31 percent of the increase, and 3,000 rail trips are carried free downtown. About 34 percent of the ridership increase may be attributed to rail service. The chairman of the transit authority, Raymond Gallagher, stated that "What is gratifying is the increase



SOURCE: Maximum load point rider counts

FIGURE 6 San Diego South Bay bus and rail ridership.

in ridership is not due to bus riders transferring to the rail system, but this new ridership increase is due to first-time riders who have never boarded a bus to get downtown" (*35*). The business community reported a 20 percent increase in downtown commercial activity as a result of rail service on this one line. Pittsburgh, Pennsylvania, and Portland, Oregon, reported similar results.

Portland

A 15-mi eastern radial rail line opened in Portland in 1986. Declining ridership on the all-bus system became increasing ridership on the new combination system. The cost per passenger declined. Light rail is now carrying 11 percent of the passengers on 4 percent of the service. The cost per rail passenger-mile is only 20 cents, compared to 40 cents by bus (*36*). The synergistic effect has now increased the number of bus riders.

Sacramento

With 15 million linked transit trips in 1986, the transit system of Sacramento, California, is one of the smallest to restore rail transit. One new light rail line, operating as two radials from downtown, is carrying 3.7 million annual passengers, 24 percent of the system's ridership on 13 percent of the vehicles. One fourth of the riders are new to transit, and many use suburban park-and-ride facilities. Service is too new to compile sufficient data, but 81 rail employees are producing 14 percent more passenger-miles per employee than bus employees (*37*).

CONCLUSIONS

In most cities served by buses exclusively, transit riding has declined 75 percent over the past 40 years. Exclusive busways have not made much difference absolutely, but they have helped relatively. In 11 areas with updated rail transit facilities, ridership has increased markedly, often by more than 100 percent. In two of these areas, the transit systems are attracting more ridership than they did when gasoline and tires were rationed. It appears that rail transit makes a great difference in ridership attraction, with attendant benefits (*38*).

Because transit use is a function of travel time, fare, frequency of service, population, and density, increased transit use can not be attributed to rail transit when these other factors are improved. When these service conditions are equal, it is evident that rail transit is likely to attract from 34 percent to 43 percent more riders than will equivalent bus service. The data do not provide explanations for this phenomenon, but other studies and reports suggest that the clearly identifiable rail route; delineated stops that are often protected; more stable, safer, and more comfortable vehicles; freedom from fumes and excessive noise; and more generous vehicle dimensions may all be factors.

Those engaged in alternatives analyses and similar studies would be well advised to consider these differential factors before making service recommendations or traffic relief assumptions. Future problems with air pollution, congestion, and funding may all be seriously affected by these considerations.

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Use of Productivity Factors in Estimating LRT Operating Costs

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Estimation of annual operations and maintenance (O&M) costs is an important component of the alternatives analyses for proposed light rail transit (LRT) systems. UMTA's recommended method for estimating O&M costs involves developing productivity-based cost models. In this paper, data are assembled on several key productivity relationships—those most central to LRT O&M cost models—from existing LRT systems over several years, and the implications of these data for estimating O&M costs of proposed systems as part of the alternatives analysis procedure are considered. Operations and maintenance productivity rates are compared among LRT properties, and the year-to-year stability of rates within properties are examined. Two basic data sources are used: the annual UMTA Section 15 data base and the results of research conducted among a group of new and old LRT properties to refine the information provided in Section 15 and other published sources. Analysis of the Section 15 data reveals wide apparent divergences in productivity rates among systems, as well as substantial year-to-year instability in the productivity data of several LRT systems. Several explanations are offered for these patterns, and implications for LRT O&M cost estimation methods are discussed.

It is increasingly common for cities that have for many decades been served only by bus transit to consider introducing light rail transit (LRT) systems. In virtually every jurisdiction in which new LRT systems have been considered, a formal "alternatives analysis," prepared according to detailed UMTA guidelines (*1*), has been conducted. One important component of these alternatives studies is the estimation of the annual operations and maintenance (O&M) costs of proposed LRT systems.

UMTA's recommended method for estimating O&M costs involves the development of productivity-based cost models. Holec and Peskin (*2*) reported on the application of this method to the Houston Transitway Alternatives Analysis in 1981. Since then, the method has been used in numerous alternatives analyses, including recent studies in Baltimore, Maryland; Milwaukee, Wisconsin; Salt Lake City, Utah; and Austin, Texas. The method mathematically relates underlying productivity measures, such as vehicle maintainers per vehicle-mile traveled, to annual measures of transit output and to unit factor prices, so that annual costs for specific operations or maintenance activities are derived on a line item basis. As an illustration of this method, the general form of a resource buildup equation for vehicle maintenance mechanics is as follows: Annual vehicle maintainer cost = annual vehicle-miles × vehicle maintainers per vehicle-mile × average annual hours worked per maintainer × average hourly wage for vehicle maintainers × fringe benefit rate.

To derive such resource buildup models for cities that do not have LRT systems, it is necessary to obtain productivity rates from existing systems in other jurisdictions and apply those rates to the LRT system that is being planned, under the assumption that the productivity relationships of existing systems would apply to the new system. The purpose of the work described in this paper was to assemble data on several key productivity relationships—those most central to LRT O&M cost models—from existing LRT systems over several years and to consider what implications these data have for estimating O&M costs of proposed systems as part of the alternatives analysis procedure.

In this paper, operations and maintenance productivity rates among LRT properties are compared, and the year-to-year stability of rates within properties is examined. Two basic data sources are used: the annual UMTA Section 15 data base and the results of research conducted among a group of new and old LRT properties to refine the information provided in Section 15 and other published sources. Analysis of the Section 15 data reveals wide apparent divergences in productivity rates among systems, as well as substantial year-to-year instability in the productivity data of certain LRT systems. Several explanations are offered for these patterns, and implications for LRT O&M cost estimation methods are discussed.

SYSTEMS SURVEYED AND DATA SOURCES

The LRT systems surveyed include seven older systems (in Boston, Massachusetts; Cleveland, Ohio; New Orleans, Louisiana; Newark, New Jersey; Philadelphia, Pennsylvania; Pittsburgh, Pennsylvania; and San Francisco, California) and four newer systems (in Buffalo, New York; Portland, Oregon; Sacramento, California; and San Diego, California). For several reasons, the UMTA Section 15 data base was used as one of the basic information sources. First, UMTA's technical guidelines for alternatives analysis recommend building up operations and maintenance cost functions according to Section 15 "function codes"—that is, the functional breakdown of costs required under the Section 15 reporting system. As a result, the Section 15 data base is an obvious source of data for cost model development because its data naturally fit the prescribed model format.

Second, Section 15 data allow relatively uniform data def-

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initions over time and among properties, so they appear to be the best data to use for making intrasystem and time series comparisons. Although several studies of Section 15 data have indicated that reporting errors are common in the Section 15 data base (*3*), the detailed reporting instructions sent to transit systems each year and the mandatory audit procedures under the Section 15 program lend a measure of credibility and uniformity to the data base. There is some evidence that Section 15 data have improved over time.

Finally, Section 15 data are readily available and can be obtained at relatively little cost. This factor is important in alternatives analysis procedures because if the data collection schemes used in the O&M cost estimation task are costly and time-consuming, they will drain resources from other important tasks, such as patronage forecasting.

The other basic data source is research performed as part of a staffing plan for a new LRT system that is under development (henceforth referred to as the new LRT study). During this effort, a number of staffing plans were collected from presentations at the 1988 TRB-sponsored LRT conference (May 8–11, 1988, in San Jose, Calif.). Current staffing rosters and operating statistics were also obtained directly from a number of LRT properties. Additional telephone contacts were used to clarify some of the earlier information. Data were collected directly in this way from new LRT systems in Portland, Buffalo, Sacramento, and San Diego, and from the Newark City Subway.

RESEARCH FINDINGS

The key finding of the in-depth research was that there is little similarity in measured productivity rates among properties. In part, the variability among properties can be attributed to differences in equipment, labor practices, environmental conditions, and operating procedures. It also appears, however, that much of the variation in productivity rates among systems may be due to differences in data definitions or errors in data reporting and collecting procedures. One indication of this problem is the extreme year-to-year variability observed within properties. We believe that this variability cannot be explained by actual underlying changes in productivity. Because of these results, it is suggested that extreme caution be used in applying productivity factors derived from Section 15 data to the prediction of operating costs for a new LRT system.

Some possible explanations for the variability within the Section 15 data are presented in the following sections. In these sections, we present some specific examples of the types of labor productivity factors in which practice and statistics vary widely.

PRODUCTIVITY RATE COMPARISONS

Together, the eight O&M cost categories examined in detail in this section typically make up about 75 percent of all LRT operations and maintenance costs. The data presented for the older systems are from 1982–1985, whereas the information for the new systems reflects their recent opening dates. For some systems, an examination of Section 15 data reported between 1979 and 1981 reveals extreme productivity rate values. Because of these extreme values, which were almost certainly the result of initial misunderstandings about data definitions or other problems associated with the break-in period for the program, Section 15 data from years before 1982 are not used.

Vehicle Operator Productivity

The annual revenue train hours per revenue vehicle operator is a measure of operator productivity that lends itself readily to the resource buildup approach to O&M costs. Table 1 provides this information for the systems studied. This table was derived from Section 15 data by adjusting the annual revenue vehicle hours per revenue vehicle operator by the ratio of the average number of trains in peak service to the average number of vehicles in peak service.

Variations in the productivity rate principally reflect differences in labor agreements and crew scheduling practices, such as differences in overtime practices, split shift and guaranteed day provisions, and the "fit" between cycle times and an eight-hour work shift. However, more detailed knowledge of the staffing practices of the various properties produces other explanations. Some properties find it better to retain fewer operators on the roster but pay them overtime, whereas others minimize overtime pay and keep a larger extra board. On occasion, both Cleveland and Newark have trained bus drivers as rail operators but have not put them on a separate rail operators' roster. These operators are used as extra operators when needed but are not counted for Section 15 reporting.

In another example, Boston, Cleveland, and San Francisco operate multicar trains but require an operator on each car to collect fares. This practice should give the appearance of lower productivity by the operator (measured in train hours) when compared with properties that operate multicar trains with only one operator. It should be noted, however, that the San Diego case does not support this hypothesis. One possible explanation is that other factors are at work, such as overtime or ability to use part-time workers. Table 2 gives staffing versus peak vehicles in operation for four new LRT systems, which all use a single operator per train.

Because averages from other systems are not likely to be an accurate reflection of the terms of the labor agreement or current practice on any specific property, another approach to determining operator labor costs was used in the new LRT study. The first step in this approach was to create an initial

TABLE 1 ANNUAL REVENUE TRAIN HOURS PER REVENUE VEHICLE OPERATOR

	Year			
System	1982	1983	1984	1985
Boston	471.7	911.5	–	1057.9
Cleveland	541.4	677.3	566.7	555.5
New Orleans	1552.8	1493.2	1991.6	1826.1
Newark	1707.8	1692.2	1323.0	1987.5
Philadelphia	1262.0	1545.0	1664.5	1294.0
Pittsburgh	1069.7	1312.2	1235.5	1847.6
San Francisco	1166.3	1213.5	1466.3	1264.9
San Diego	938.6	1072.6	1040.3	989.8
Buffalo				1667.7[a]
Portland				1035.7[a]

[a] 1987 data.

TABLE 2 STAFFING VERSUS PEAK VEHICLES IN OPERATION

System	Peak Vehicles	Operators
San Diego	25	31 full-time, 18 part-time
Portland	22	34
Buffalo	23	23
Sacramento	23	23

operating plan, complete with headway book, and thereby to determine the number of platform hours required to operate the system. The next step was to determine the number of platform hours per full-time equivalent (FTE) operator per year. Dividing that number into the number of platform hours produced the number of FTE operators the system would require.

The O&M cost portion of the new LRT study used 1,500 platform hours per FTE operator per year, which appeared to be a representative average of a number of properties and was reasonably close to current experience of the property that was expected to operate the new system. On this basis, the new LRT line was predicted to require 33.25 FTE operators. After cutting runs on the basis of the current labor agreement and using the same headway book, the property's schedule department suggested that the line could be operated with only 30 operators. Because the two estimates came to within 10 percent of each other, this approach (using platform hours per FTE operator per year) appears to be reasonable. It permits an existing property to tailor the productivity more closely to the property's experience, if applicable. Even if the existing operation is motor bus only, the measure of platform hours per FTE operator will reflect existing labor practices that are likely to carry over to the new LRT operation.

Operations Support Personnel

Table 3 presents the ratio of revenue vehicle operators (FTE) to operations support and supervisory personnel (FTE), a category that includes schedulers, dispatchers, and administrative personnel specifically assigned to the operating departments. It may also include car hostlers, but these employees may alternatively be categorized as vehicle maintenance support personnel.

This table is based on the schedule of labor equivalents presented in Table 3.14 of the annual Section 15 reports. The values range from a high of 8.33 operators per support and supervisory FTE, reported by Philadelphia in 1985 (which appears out of line with Philadelphia's other years), to a low of 0.92, reported by Pittsburgh in 1985. All systems, except San Diego, report operator-to-support and -supervisory ratios that fluctuate greatly, often by as much as 50 percent, between fiscal years.

The planners of the new system under study intended to incorporate operating personnel in an existing transportation division so that no additional support staff would be required. Supervision was to be provided by existing on-street supervisory staff. Operations were to be controlled by wayside signals and the rule book. Switching was to be operator-controlled, except in the yard during weekday peak periods. Neither mimic boards nor central control posts were contemplated. As a result, it was determined that only one additional transportation support/supervisory position was required for this particular application. It was also determined that if the LRT system under study were to operate as a stand-alone, seven FTE transportation support and supervisory staff positions would be required.

TABLE 3 REVENUE VEHICLE OPERATORS PER OPERATIONS SUPPORT AND SUPERVISORY PERSONNEL

	Year			
System	1982	1983	1984	1985
Boston	1.86	0.94	-	2.09
Cleveland	3.19	2.58	1.34	3.17
New Orleans	4.84	4.58	8.04	4.00
Newark	5.67	5.67	5.33	2.97
Philadelphia	2.87	7.55	4.42	8.33
Pittsburgh	6.52	3.69	2.07	0.92
San Francisco	7.56	5.53	5.47	5.14
San Diego	2.10	2.30	2.55	2.00
Buffalo				0.90[a]
Portland				2.06[a]
Sacramento				1.10[b]

[a] 1987 data.
[b] From Sacramento staffing plan.

TABLE 4 ANNUAL VEHICLE MILES PER REVENUE VEHICLE MAINTAINER

	Year			
System	1982	1983	1984	1985
Boston	26,167	25,958	-	58,819
Cleveland	29,926	26,030	33,165	35,181
New Orleans	23,254	22,978	30,185	52,316
Newark	40,686	43,977	31,536	34,062
Philadelphia	33,076	54,003	36,602	50,382
Pittsburgh	39,733	20,769	22,975	37,224
San Francisco	19,355	20,528	16,656	38,131
San Diego	177,467	144,709	128,976	158,179
Buffalo				49,831[a]
Portland				65,034[a]
Sacramento				138,888[b]

[a] 1987 data.
[b] Sacramento data from interview; annual miles estimated.

Vehicle Maintenance Labor

Table 4 reports the productivity measure of annual vehicle-miles per revenue vehicle maintainer. The values for this measure were calculated on the basis of the labor equivalents presented in Table 3.14 and the annual vehicle-miles reported in Table 3.16 of the Section 15 reports. The range is extremely wide, from more than 175,000 annual vehicle-miles per maintainer in San Diego's best year to as few as 20,000 in Pittsburgh and San Francisco in their worst years.

Explanations for the width of the range include differences in labor agreements; the technical quality and training levels of the work force; different equipment, servicing cycles, and maintenance requirements of the fleets in various cities; and differences in the overall condition and reliability of the various fleets. Two other factors that may help explain the unusually high productivity reported for San Diego are the relative "youth" of the fleet and San Diego's relatively heavy

TABLE 5 CARS PER ELECTROMECHANIC

System	Fleet Size	Electromechanics	Cars per Electromechanic
Sacramento	26	7[a]	3.71
Newark	24	8	3.00
Portland	26	13	2.00
San Diego	30	18[a]	1.67
Buffalo	27	21	1.29

[a]Plus supervisor.

reliance on contract maintenance (indicated by the use of ~14 percent of their reported maintenance expenses for purchased services).

The alternative approach used for the new LRT study involved establishing a measure of vehicle maintainers to fleet size, expressed as cars per electromechanic. The telephone interviews included a fairly detailed investigation of the staffing plans and job descriptions for maintenance department staff, combined with measures of time to perform typical tasks (e.g., nightly inspection, primary mileage-based preventive maintenance inspection). For the new system, a scenario describing the work that would be done in house and the work that would be contracted out was also developed.

Table 5 presents the cars per electromechanic ratio for five properties. The ratio ranged from a high of 3.71 vehicles per vehicle maintainer to a low of 1.29. The telephone interviews also revealed widely varying job descriptions:

- On one property, vehicle maintainers also move cars around the yard to prepare the morning lineup and, in effect, perform a nightly running systems check as they do so.
- On another property, some of the staff counted as vehicle maintainers for the Section 15 report are semipermanently assigned to repair fare vending and change-making machines, and thus they do not really work on revenue vehicles.
- Some properties still have cars under warranty, so manufacturers' staff members are performing warranty work. One property indicated that they would have to expand car maintenance staff when car mileage reached the point at which a general inspection was required.

Within the revenue vehicle maintenance operation, however, there appeared to be somewhat more consistency in the amount of time required for specific tasks. Thus a number of properties reported that the nightly systems check took about 20 minutes per car and that the first mileage interval inspection (typically performed at 3,000–4,000 miles) took about 12 work hours. This information was combined with assumptions about the car configuration and a calculation of annual fleet mileage to calculate inspection labor hours. Inspection labor hours per year were calculated as follows:

- Nightly safety checks (0.33 hours × 26 cars × 365 days): 3,160;
- Weekly pit inspection (0.67 hours × 26 cars × 52 weeks): 910;
- Mileage inspections (4,000 mile intervals): 6,430;
- Total annual inspection hours: 10,500.

This comes to seven electromechanics, on the basis of an assumed 6.8 productive staff hours per worker shift and 220 worker shifts per staff year. The staffing plan ultimately included two additional electromechanics for running repairs that are not covered under warranty.

TABLE 6 VEHICLE MAINTAINERS PER VEHICLE MAINTENANCE SUPERVISOR

	Year			
System	1982	1983	1984	1985
Boston	3.9	3.0	–	1.8
Cleveland	4.4	4.4	2.5	2.3
New Orleans	5.8	6.2	8.2	4.3
Newark	14.0	13.0	14.0	16.0
Philadelphia	2.9	2.3	2.1	1.9
Pittsburgh	1.5	3.8	2.1	2.2
San Francisco	2.2	1.9	2.5	4.8
San Diego	1.5	2.8	2.6	2.7
Buffalo				2.1[a]
Portland				2.4[a]
Sacramento				2.6[b]

[a]1987 data.
[b]From Sacramento staffing plan.

Vehicle Administration/Supervision Labor

The Section 15 staffing table includes a category for FTEs for vehicle maintenance administration labor. Table 6 presents Section 15 statistics for a variety of years and systems. This table, produced from data in Table 3.14 of the Section 15 reports, again demonstrates that productivity measurements (efficiency of supervision, in this case) fluctuate dramatically between systems and even between years in a given system. For 1985, the values range from a high (most efficient) of 16.0 for Newark to a low of 1.8 for Boston.

Supervisory or administrative requirements are a function of many factors, including the number of locations at which maintenance is performed, the hours during which the maintenance facilities are staffed, the system's job classifications and practices relating to monitoring and supervision, and the ability to employ "working foremen" or similar quasi-supervisory staff, to name a few. If Table 6 values were applied to a system with 30 vehicle maintainers, 12.5 supervisory staff would be used for cost estimating purposes if Portland's ratio were applied, but only 6.25 would be used if San Francisco's 1985 ratio were chosen. Development during O&M costing of a staffing structure designed specifically for a new system appears much more likely to yield an accurate result than does use of an average productivity factor from the table.

Vehicle Servicing Labor

Although the Section 15 data include a category for vehicle maintenance support labor, these data were not analyzed in the same way as were data for the other maintenance categories, primarily because the category may include such diverse job classifications as parts clerk, mileage clerk, stockroom clerk, and car cleaner. There is no way to tell from the Section 15 data, however, which categories were included for any given system. It thus appears to be much more appropriate to use a detailed labor buildup approach for O&M costing in this category.

TABLE 7 CARS PER CAR CLEANER

System	Fleet Size	Cleaners	Cars per Cleaner
Newark	24	2	12.0
Portland	26	4	6.5
Buffalo	27	6	4.5
Sacramento	26	6[a]	4.33
San Diego	30	7–10	3.0–4.33

[a] Plus supervisor.

TABLE 8 TRACK MILES PER MAINTAINER

System	Single-Track Miles	Maintainers	Track-Miles per Maintainer
San Diego	41.0	12	3.42
Sacramento	25.6	11	2.33
Portland	28.1	23	1.22
Newark	8.5	20	0.43
Buffalo	12.4	69	0.18

Table 7 presents data for employees engaged in car cleaning on a number of properties, based on the interviews described earlier. The interviews also revealed a significant difference in the level of detailing that different properties plan for their car cleaning: whether cars are washed nightly, how often interiors are mopped and the glass is polished, and so on. The amount of detailing required does not necessarily reflect variations in cleanliness standards because the different properties operate under different climatic conditions and passenger loads.

As previously mentioned, some systems include car hostlers in the maintenance employee count, whereas others include these workers in the transportation department count. It was thus deemed advisable to separate the functions clearly in the interview process and in the productivity measure. The productivity ratios for this category of labor ranged from 12 to 3.0–4.3 cars per cleaner. The latter range was estimated by San Diego, where car cleaning is contracted out; the staffing level is determined by the contractor.

Nonvehicle Maintainers

Nonvehicle maintenance functions include maintenance of power and signals, track, ballast, right-of-way, structures, drainage, fare collection equipment, and communications. Staffing typically includes a line crew, which deals with all items involving electrical power, and a track crew, which deals with all items that do not involve electrical power. In case of need, some systems' labor agreements permit cross-use. Other functions performed by staff in this category may include station platform cleaning, trash pickup along private right-of-way, and maintenance and repairs on the physical plant (buildings, station shelters, etc.). Some properties count the fare equipment repairers as electromechanics and include them in the vehicle maintainer count, whereas others include them in the nonvehicle maintainer category.

Table 8 presents the productivity ratio of track-miles per maintainer for selected properties. The range extends from 3.42 miles per maintainer in San Diego to 0.18 miles per maintainer in Buffalo. The properties that have a large number of nonvehicle maintainers relative to their trackage have underground stations that require extensive and frequent cleaning. Buffalo also uses its nonvehicle maintainers to remove snow along the downtown mall portion of the right-of-way in the winter. The other new properties have relatively simple, basic station stops and no snow-removal duties. Again, averages mask local conditions.

TABLE 9 PEAK VEHICLES PER FARE INSPECTOR

System	Peak Vehicles	Inspectors	Peak Vehicles per Inspector
San Diego	25	12[a]	2.08
Buffalo	23	12	1.92
Sacramento	23	6[a]	3.83
Portland	22	9	2.44

[a] Plus supervisor.

Fare Inspection

A new category for staffing, applicable to systems using the Proof-of-Payment (POP) fare system, is fare inspection. This job classification is not yet reported separately in the Section 15 reports, although it may be included in another staff grouping. New properties have widely differing staffing practices for fare inspection. It is difficult to make comparisons because of differences in the amounts of service provided. For example, Portland and Sacramento currently operate 15-minute headways during midday base hours and 30-minute headways during evenings. Buffalo operates 10-minute headways during midday base hours and 20-minute headways in the evenings. San Diego's fare inspectors are counted in the staff of the Metropolitan Transit Development Board instead of the San Diego Trolley staff, further complicating the analysis. Table 9 presents the number of peak vehicles per fare inspector for four POP systems. The range is from 1.92 for Buffalo to 3.83 for Sacramento, reflecting different levels of enforcement and coverage as well as scheduling. In addition, it should be noted that the selection of the level of enforcement is influenced by the level of fare evasion deemed locally acceptable.

Power Consumption

Table 10 presents information on the average rate of electric power consumption for vehicle propulsion. The indicator, kilowatt hours of propulsion energy consumed per vehicle-mile (kwhr/veh-mi), reflects a variety of factors, including type of vehicle, type of propulsion power distribution and pickup system used, frequency of station stops, average vehicle speeds, terrain, and type of braking system.

This productivity measure, as derived from Table 3.18 of the Section 15 data, exhibits the least fluctuation within systems of all the measures presented, although there is a broad range of values among systems. Lowest power consumption rates are found in New Orleans and San Diego, averaging around 4 kwhr/veh-mi over the 4-year analysis period. By contrast, Boston and Philadelphia rates are typically in excess of 10 kwhr/veh-mi. The relative consistency within systems

TABLE 10 KILOWATT HOURS OF PROPULSION ENERGY PER VEHICLE-MILE

	Year			
System	1982	1983	1984	1985
Boston	14.3	11.1	10.3	10.1
Cleveland	5.2	12.7	9.0	6.1
New Orleans	4.5	4.0	4.0	4.0
Newark	6.2	7.2	6.8	6.9
Philadelphia	9.8	10.3	10.5	11.9
Pittsburgh	8.0	10.6	7.4	8.9
San Francisco	12.6	12.7	6.4	9.6
San Diego	4.3	4.0	4.7	4.5
Buffalo				11.8[a]
Portland				7.2[a]

[a] 1987 data

can be partially attributed to the lack of ambiguity in the measure. By contrast, measurements of labor efficiency are much more subject to definitions of terms and potential ambiguities in staffing categories.

CONCLUSIONS

Productivity-based models for O&M costs in LRT operation have tended to depend on productivity factors inferred from Section 15 data. These data have proven to be highly variable over time within individual systems, as well as over systems within a given year. Furthermore, the staffing categories are subject to different interpretations, so that strict comparability cannot be assumed among systems. Contracting out, different labor practices, different forms of organization on various properties, and different operating scenarios all combine to make the use of Section 15–based productivity factors somewhat unreliable.

An alternative approach is to use a resource buildup method that relies on a detailed O&M plan that lends itself to fairly detailed staffing conjectures. The alternative productivity factors presented in this paper are examples of the application of this approach, which is capable of being much more system-specific in its productivity factors and hence can produce more accurate O&M cost estimates. Such issues as the integration of the LRT operation into an existing structure versus its operation as a stand-alone system will have significant bearing on staffing and hence O&M costs. These issues are far more accurately handled by the alternative approach presented here than by use of averages derived from Section 15 data.

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Simulation Study To Evaluate Spare Ratios in Bus Transit Systems

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A simulation model was developed to investigate proper choice of the spare ratio to maintain a desirable level of service dependability. The objective of the model was to study the effects of the time between bus breakdowns and the time to repair broken buses, as well as other characteristics of the system, on the value of the spare ratio and the overall performance of the transit system. The model was successfully validated and used to simulate and study the bus operations of an existing transit system. The model can be adapted to simulate the operations of different bus transit systems.

The overall reliability of the service provided by a bus transit system is a function of a number of factors, including mechanical reliability of buses, availability of spares to replace broken buses, and total time elapsed until disabled buses are fixed and sent back to operation.

The main objective of the research described in this paper was to investigate the proper number of spare buses needed to maintain a desirable level of service reliability. The investigation includes a study of the effects of bus mechanical reliability, time to repair failed buses, and repair schedule policies on the spare ratio level. The spare ratio is defined as the ratio of the number of spare buses in the fleet to the maximum number of buses scheduled at peak periods. A simulation model was developed to examine

- The relationship between frequency of bus breakdowns and the spare ratio and its effect on the level of service;
- The relationship between the number of mechanics working at the repair garage (or repair turnaround) and the spare ratio;
- The relationship between the frequency of breakdowns of individual bus components and the spare ratio; and
- The relationship between scheduling policies practiced at the repair shop and the spare ratio level required.

A bus transit system with a fleet of 57 buses was selected from a hilly, medium-sized city in the Mid-Atlantic region as the basis for the simulation model. The model can also be used to simulate the operation of other transit systems if some of the input parameters and parts of the model are changed.

LITERATURE REVIEW

Although a great deal has been written about issues related to bus maintenance, no literature has specifically addressed the spare ratio. Several researchers have studied bus systems and developed models to predict or enhance performance indicators. These indicators have usually been linked to operating costs (*1, 2*), preventive maintenance policies (*3*), resource use (*4*), repair scheduling (*1*), bus scheduling and bus boarding time (*5*), passenger waiting and traveling time (*6*), transit system reliability (*7*), and other issues, all either directly or indirectly related to the spare ratio problem. In general, research reported in the literature can be classified into one of five areas:

- *Data collection and preparation.* In this area, Maze et al. (*8*) provided methods to obtain information on maintenance planning and fleet management. Maze and Dutta (*9*) illustrated a statistically based method to quantify and compare life characteristics of bus components in an operational setting. Kosinski et al. (*10*) also provided methods to generate statistics on bus component failures.
- *Application of universal methodologies and guidelines.* In 1981, UMTA attempted to develop standard maintenance guidelines to be used by transit systems (*11*) but had to abandon its effort for lack of agreement on universally accepted standards. Tradeoffs between capital costs, operating expenses, and maintenance work were addressed by Dutta et al. (*1*) and Wilson (*2*), but no guidelines were developed because of the unique characteristics of the individual transit systems.
- *Analysis of relationships between resources and system performance.* Maze et al. (*12*) developed a simulation model of a hypothetical maintenance system to examine different policies in maintenance planning. Maze et al. (*13*) and Sinha and Bhandri (*3*) developed simulation models to investigate relationships between system performance and availability of resources.
- *Analysis of relationships between environmental conditions and system performance.* Effects of terrain, climate, fleet age, and other factors on maintenance manpower requirements were investigated by Wilson (*2*) and Drake and Carter (*4*).
- *Impact of maintenance policies on system performance.* Sinha and Bhandri (*3*) investigated the relationship between preventive maintenance policies and system performance. Guenthner and Sinha (*7*) studied the impact of maintenance strategies on service reliability. Dutta et al. (*1*), and Martin-Vega (*14*) also investigated the impact of repair scheduling policy on the performance of bus transit systems.

MODEL INPUT

Information collected from the transit system under consideration consisted primarily of bus breakdown records and

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TABLE 1 BUS SCHEDULE

Group	Total No. of Buses	No. Scheduled on Weekdays (Saturdays)				
		Morning		Mid-Day	Evening	
		Off-Peak	Peak	(Off-Peak)	Peak	Off-Peak
1. Bluebird	10	2(6)	6(6)	2(6)	6(6)	2(6)
2. National	5	2(2)	4(2)	2(2)	4(2)	2(2)
3. AM General	7	0(0)	0(0)	0(0)	0(0)	0(0)
4. GMC	23	15(15)	22(15)	15(15)	22(15)	15(15)
5. Flxible	12	10(11)	12(11)	10(11)	12(11)	10(11)
Total	57	29(34)	44(34)	29(34)	44(34)	29(34)

repair data for system operation during fiscal year 1986–1987. This information was used to produce summaries and statistical distributions for the number of miles between breakdowns and repair times for the individual components of different bus groups used in the system. Data were collected for only a single year, but they cover several types of buses with varying ages.

In generating breakdowns in the simulation model, it was assumed that failure patterns vary between types of buses but are the same for buses of the same type and age. The buses were therefore categorized into five groups according to their type and age. The number of buses in each group is given in Table 1.

Data files were maintained for work performed on more than 200 individual components. To simplify the simulation input, these components were grouped into the following 19 categories, each containing several components:

- Scheduled state inspections;
- 3,000- and 9,000-mi inspections;
- 6,000-mi inspections;
- 12,000-mi inspections;
- Axles;
- Braking system;
- Cooling system;
- Drive line;
- Electrical system;
- Fuel system;
- Fare box;
- Heating system;
- Air conditioning system;
- Body, seats, doors, and windows;
- Engine;
- Steering system;
- Suspension system;
- Transmission system; and
- Other repairs and maintenance.

A team of 12 mechanics was scheduled for work during the morning shift (7:00 a.m.–3:00 p.m.), and teams of 5 mechanics were scheduled for the other shifts (3:00–11:00 p.m. and 11:00 p.m.–7:00 a.m.), 6 days each week, Monday through Saturday. During the second and third shifts, minor jobs such as cleaning, washing, checking fuel, repairing lights, fixing flat tires, and mending radio equipment were performed.

Buses are scheduled for operation between 4:35 a.m. and 12:55 a.m., weekdays and Saturdays, according to the schedule presented in Table 1. On Sundays, five buses from Group 5 are scheduled to operate for 2 hours only. The spare ratio for this system can thus be calculated as 13/44, or 29.5 percent.

DATA PREPARATION

A data base was created with 6,466 records, one for each inspection or repair job completed. This data base was used to generate distributions for time between failures and repair times.

Distributions of Time Between Failures

Each of the five bus groups was considered a separate entity in the simulation model. This approach was easier and more practical than considering each bus alone. Buses of the same group were assumed to be similar in all aspects and to possess the same characteristics, including failure patterns.

All records were classified into five files, corresponding to the bus groups. Each of these files was then broken down into 19 different smaller groups, corresponding to the 19 categories of bus components. Thus $5 \times 19 = 95$ different groups were obtained and used to generate time between failures for each component category within a bus group.

The repair data contained the date of the repair, which was assumed to be close enough to the breakdown date. The bus mileage at the time of breakdown, however, was not recorded. Because the number of buses on the road was not constant at different times and dates, it was necessary to convert the time between breakdowns into mileage between breakdowns. The number of inspections performed at 3,000-mi intervals was determined and used to calculate the total mileage per bus group per year and the average mileage that each bus was driven per day. For each bus group, the average speed was estimated as the ratio of total miles to total number of hours on the road per year.

The average mileage per day for each group of buses and the number of days between breakdowns were used to obtain frequency distributions for miles between breakdowns for all component categories within each bus group. These distributions were then used to generate breakdowns in one of three ways:

- *Exponential distribution.* Data for the group were successfully tested to fit the distribution. The χ^2 goodness-of-fit test was used for this purpose.
- *Cumulative probabilities (empirical distributions).* If no standard statistical distribution could fit the data, this method was used directly to generate miles between breakdowns.
- *Generation of breakdowns.* If few observations were available (e.g., two or three breakdowns), the exact numbers of breakdowns were generated at equal intervals during the year. This method was also used for inspections.

Repair Time Distributions

To generate repair times, individual bus components were grouped into the 19 categories identified earlier. Unlike failure rates, repair times were not assumed to depend on the bus group. The 6,466 records for repair times were thus placed into only 19 data groups. The Shapiro-Wilk and Kolmogorov-Smirnov nonparametric tests were used to test whether the repair times for each category followed a normal distribution.

The units used for the repair time were small enough that the data could be considered continuous. It developed that none of the groups followed a normal distribution. Grouping the data into a larger number of more homogeneous categories could lead to better normal fits, but this procedure would add to the complexity of the model. Because no other probability distribution could be identified to fit the data closely, cumulative probabilities were used directly to generate repair times.

SIMULATION MODEL DEVELOPMENT

An investigation was made of the effects of the following parameters on the desired level of the bus spare ratio:

- Number of mechanics on duty,
- Time between bus breakdowns, and
- Policies practiced in the repair shop.

The simulation model was designed to provide the following information under various operating conditions:

- Usage of mechanics,
- Average waiting time for repair,
- Average time spent in the repair system, and
- Percentage of time that the system is faced with a bus shortage and cannot fully meet the schedule.

To represent the transit system and its maintenance facilities as closely to reality as possible, all buses were classified into one of the following categories:

- *Active buses*. Operative and regularly scheduled for service;
- *Spare buses*. Operative but not regularly scheduled; and
- *Failed buses*. Inoperative because of mechanical failure, preventive maintenance, or inspection.

This method of classification is not standard practice; however, it was the method used by the system under consideration.

Assumptions of the Model

Various assumptions were made and maintained throughout the simulation. Failures were classified into critical and noncritical categories, in which critical failures are those that cause interruption of service and put the bus out of commission until it is fixed. Noncritical breakdowns do not interrupt the bus service but require repair work at the end of the scheduled operation of the bus. The ratio of critical to noncritical failures can be changed as a parameter in the simulation model, depending on the characteristics of the system under consideration.

When a critical failure occurs, a mechanic takes a spare bus, if available, to the location of failure. The spare bus replaces the failed one, and the mechanic either fixes the failed bus on location or tows it back to the garage, where it is scheduled for repair according to the priority set at the shop. The following order is followed when substituting a failed bus with a spare, depending on the availability:

1. Replace the failed bus with a bus from the same group.
2. Replace the failed bus with a bus from Group 3, which consisted of buses designated as spares.
3. Replace the failed bus with a bus from another group that has the same capacity.

The same order is followed when buses are scheduled for operation.

The percentage of times that a mechanic can repair a failed bus on location can be changed as a parameter in the model. It is also assumed that maintenance workers are interchangeable and can perform all repairs.

The model assumes that repair times and miles between breakdowns are stochastic in nature, but inspections are performed at fixed intervals. Maintenance equipment, tools, and replacement parts are assumed to be always available. Travel time to location of a failed bus and back to the shop is uniformly distributed between 10 and 20 min, and towing time is uniformly distributed between 20 and 40 minutes.

In general, noncritical breakdowns need smaller repair times than the critical ones. Inspections are treated as noncritical failures.

Elements of the Model

An overall flowchart of the simulation model is given in Figure 1. The model consists of five elements.

Breakdown Generation

Five entities representing the five groups of buses were considered to be subject to periodic failures. Each entity has its own attributes that define its status and characteristics. Miles between breakdowns were generated separately for each component category within each bus group according to its predetermined probability distribution.

As the simulation progresses, mileages are accumulated for each bus group according to the number of active buses on the road for that group and their average speed. The number of buses on the road changes with time and depends on both operation schedule and bus availability. The time of the next failure was therefore not easy to predict because it was constantly changing with the number of buses on the road for the group.

Scheduled Changes in the Number of Buses

The number of buses scheduled for operation changes several times during each day, Monday through Friday. Different schedules are also planned for Saturdays and Sundays. To simplify the bus operation schedule in the simulation, a complete cycle with 39 periods was developed for the entire week and repeated throughout the simulation. Whenever the num-

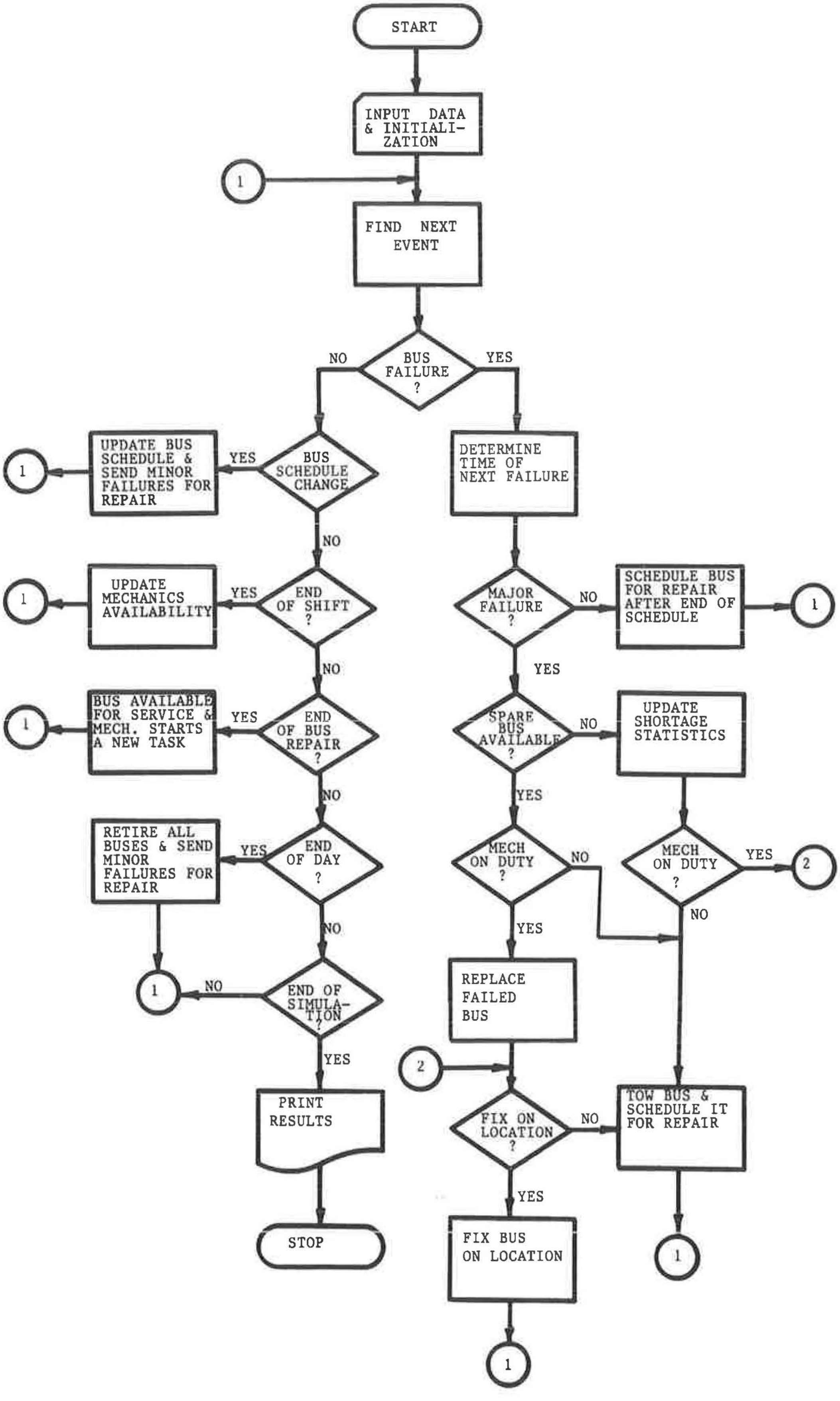

FIGURE 1 Flowchart of the simulation model.

ber of buses in operation was reduced, during the change from a peak period to an off-peak period or at the end of the day, buses with noncritical breakdowns were pulled first and scheduled for repair.

Scheduled Changes in the Number of Mechanics on Duty

Different numbers of mechanics are scheduled to work during the three daily shifts, Monday through Saturday. A complete cycle of 19 shifts (three 8-hr shifts for Monday through Saturday and one 24-hr shift with no mechanic for Sunday) was used for the entire week in the simulation.

The morning shift is usually staffed with more mechanics than the other two shifts. For simplicity, it was assumed that when the mechanics change between shifts, the new crew continues the work started by the old one. If the number of mechanics between shifts increased or decreased, appropriate action, such as starting repair on a bus or interrupting repair work being performed, was taken.

End of Repair on a Bus

Two actions are taken whenever a repair job is completed. First, the freed mechanic checks for waiting buses and starts working on the first bus in the queue. If the queue is empty, the mechanic becomes idle, which in reality means performing other jobs such as fueling, cleaning, and so on. Second, the bus that was just repaired is returned to service, either as an active bus or as a spare, depending on the number of buses scheduled for service and the number of buses available.

End of the Day

The end of the day is defined as the time at which all buses return from service. At this time, all in-service buses with noncritical breakdowns are scheduled for repair.

Program Overview

The transit system operation was simulated using a FORTRAN and SLAM II simulation program (*15*). The program starts by reading all input variables, arrays, and parameters and performing the necessary initialization. Breakdowns are then scheduled for each bus group, and control of the program is transferred to SLAM II. The SLAM II program finds the next event to occur, calls the appropriate subroutine for that event, and controls the flow of events and all operations. After a warm-up period, statistics are collected on the system performance measures. By changing the parameters of the system, these statistics can be collected under different configurations and operating policies. The main parameters that were investigated are

- Spare ratio (the value of the spare ratio was controlled by changing the number of spare buses available),
- Number of mechanics,
- Repair scheduling policies, and
- Rate of breakdown for different component categories of the five bus groups.

MODEL APPLICATION AND ANALYSIS OF RESULTS

The simulation model was successfully validated against the actual operational data of the system. The number of breakdowns per bus type, number of breakdowns per component, use of mechanics, and repair times generated by the model were compared with the actual operational values, and no significant difference was found. Sensitivity analyses were performed on the input parameters and model variables, and the model responded as expected [for details of the validation process and results, refer to the report by Iskander and Jaraiedi (*16*)].

The model was then implemented under different conditions by varying its parameters and input variables. The main objective was to investigate the effects of several parameters and variables on the value of the fleet spare ratio required to maintain a desirable level of service. The following measures of performance were selected to represent the level of service rendered to the riders and the turnaround in the repair garage:

- *System dependability*. System dependability, D, was defined as

$$D = 1 - (B_M/B_T)$$

where B_M is bus-hours of missed runs and B_T is total bus-hours of operation. The higher the number of bus-hours missed due to breakdowns, the lower the dependability of the system.

- *Time in system*. TISYS is the total time (waiting plus repair) spent by a bus at the repair shop.
- *Average number of buses in the repair queue*. This measure is represented by the variable LQU (for "length of queue").

The effects of the following parameters and variables on the desired level of the spare ratio were investigated:

- Availability of resources (mechanics) at the repair shop,
- Repair scheduling policies, and
- Rates of failure of different bus components.

The rates of failure depend on several factors, such as age of component, climate, terrain, and so on. By individually adjusting the rates of failure of the bus components, the effects of different factors on the value of the spare ratio required can be investigated.

Relationships Among the Spare Ratio, Number of Mechanics, and System Performance

Because the reliability of a bus or its components is primarily measured as a function of the mileage between breakdowns under normal operating conditions, its value does not change with the spare ratio or the number of mechanics available. A higher spare ratio, however, increases the probability of having a spare bus when one is needed. Also, a higher number of mechanics usually results in faster turnaround at the repair

TABLE 2 RELATIONSHIPS AMONG SPARE RATIO, NUMBER OF MECHANICS, AND SYSTEM PERFORMANCE

Spare Ratio (%)	Number of Mechanics at: Evening & Night Shifts	Number of Mechanics at: Morning Shift	D	TISYS	LQU
	3	5	0.9266	6.09	2.05
	3	6	0.9440	5.72	1.85
11.4	3	8	0.9520	5.56	1.70
	4	5	0.9647	4.68	1.14
	4	8	0.9662	4.55	1.10
	5	5	0.9797	4.24	0.81
	3	5	0.9824	6.09	2.06
	3	6	0.9897	5.85	1.89
20.5	3	8	0.9899	5.77	1.82
	4	5	0.9964	4.89	1.22
	4	8	0.9972	4.62	1.19
	5	5	0.9979	4.28	0.85
	3	5	0.9964	6.29	2.18
	3	6	0.9965	5.80	1.93
29.5	3	8	0.9966	5.46	1.69
	4	5	0.9986	4.84	1.20
	4	8	0.9988	4.79	1.13
	5	5	1.0000	4.28	0.81
	3	5	0.9994	5.76	1.86
	3	6	1.0000	5.52	1.68
40.9	3	8	1.0000	5.37	1.60
	4	5	1.0000	4.72	1.15
	4	8	1.0000	4.55	1.07
	5	5	1.0000	4.16	0.79

shop and improves the availability of buses. An increase in the spare ratio or the number of mechanics should therefore improve bus dependability.

Table 2 presents the relationships among the spare ratio, number of mechanics, system dependability, average time spent in repair facilities, and average number of buses waiting for repair. Statistics were collected for a duration of 1 year, which covers 223,723 bus-hours of scheduled operation. Results indicate that with the same number of mechanics, as the spare ratio increases, system dependability improves. For the same spare ratio, system dependability also improves with the increase in number of mechanics. Both time spent at the repair shop and length of the queue of buses waiting for repair (LQU) decrease with the increase in number of mechanics. Under the assumptions of the model, maintenance workload depends mainly on total bus mileage, so performance characteristics at the repair shop are not affected by the value of the spare ratio.

Plots of dependability for different numbers of mechanics against different values of the spare ratio are shown in Figure 2 and Figure 3. For a spare ratio of 11.4 percent, system dependability increases from 0.9266 to 0.9662 when the number of mechanics is increased from 5 to 8 in the morning shift and from 3 to 4 in the other two shifts. Similar conclusions

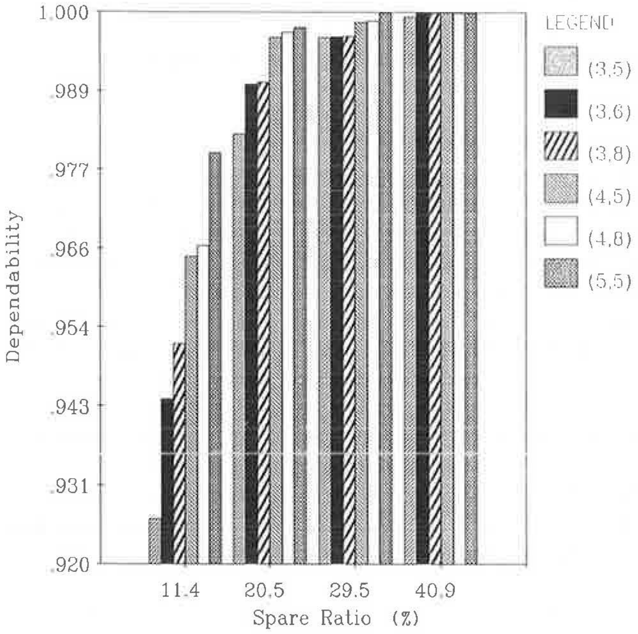

FIGURE 2 Impact of number of mechanics on dependability.

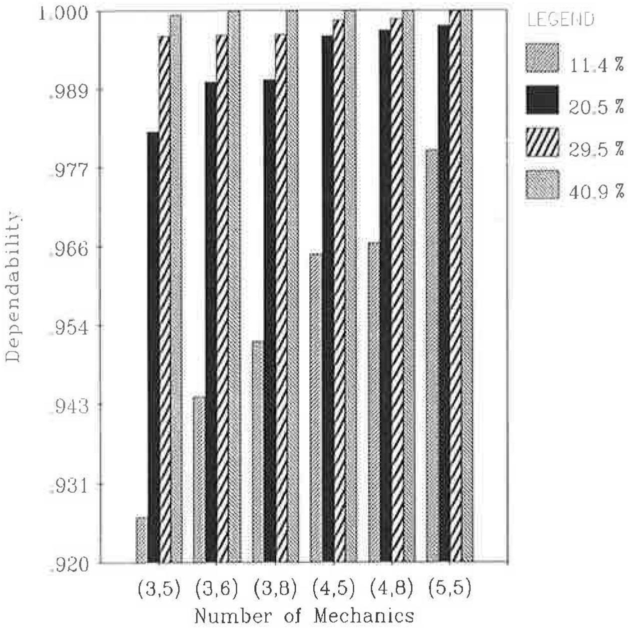

FIGURE 3 Impact of spare ratio on dependability.

TABLE 3 CHANGE IN DEPENDABILITY ASSOCIATED WITH INCREASE IN SPARE RATIO

	Spare Ratio (%)			
Number of Mechanics[a]	11.4	20.5	29.5	40.9
3, 5	N/A	.0558	.0140	.0030
3, 6	N/A	.0457	.0068	.0035
3, 8	N/A	.0379	.0067	.0034
4, 5	N/A	.0317	.0022	.0014
4, 8	N/A	.0310	.0016	.0012
5, 5	N/A	.0182	.0021	.0000

NOTE: N/A = not applicable (base system)
[a] Evening and night shifts, morning shift.

can be made with the spare ratios of 20.5, 29.5, and 40.9 percent. In addition, for a fixed number of mechanics, system dependability increases with the spare ratio increase.

These results were obtained when the percentage of critical breakdowns of the total number of breakdowns was 25 percent, as estimated by the operators and managers of the system under consideration. The high levels of dependability are not unusual in bus transit systems, where a level of 1.00 is always mentioned as a goal. In fact, a level of 0.98 can be considered low because this means that during 2 percent of the time, one or more buses cannot meet their schedules. In this system, a 0.1 percent change in dependability is translated to 0.001 × 223,723, or about 224 bus-hours of shortage.

Results also demonstrate that, as expected, TISYS and LQU decrease as the spare ratio or the number of mechanics increases. Tables 3 and 4 summarize the incremental change in dependability associated with the increase of the spare ratio and the number of mechanics, respectively.

To decide which combination of spare ratio and mechanics can best fit a system, a formal cost analysis should be performed. Factors such as cost of acquisition, maintenance cost of an additional spare bus, mechanics' salary, and so on should be investigated in the analysis.

Effect of Repair Scheduling Policy

A bus repair system consisting of eight mechanics in the main shift and three mechanics in the other two shifts, 6 days a week, was selected as the base system for all the following analyses. This combination of mechanics was selected because with more mechanics the system would not be sufficiently sensitive to changes in the parameters. A smaller number of mechanics, on the other hand, could cause long queues of buses waiting for repair. The percentage of critical breakdowns used for the base system is 25 percent, and the percentage of time that buses are fixed on location is 50 percent.

The following policies were investigated for repair scheduling:

- First come first served (FCFS);
- Schedule the bus that requires the shortest processing time (SPT) first; and
- For buses that have waited for more than a specific number of hours (8, 16, or 24 hours), use FCFS rule; if none, apply SPT rule.

The results of 20 runs on systems with spare ratios of 11.4 percent, 20.5 percent, 29.5 percent, and 40.9 percent are presented in Table 5 and Figures 4, 5, and 6. Results indicate that a significant improvement can be achieved by applying SPT policy over FCFS. It would be slightly better in most cases to apply the SPT policy and revert back to FCFS whenever one or more buses have been waiting for 16 or more hours.

These results agree, in general, with those obtained by Dutta et al. (*1*), who found that performances of transit systems vary significantly with different repair scheduling policies. They also concluded that systematic scheduling rules

TABLE 4 CHANGE IN DEPENDABILITY ASSOCIATED WITH INCREASE IN THE NUMBER OF MECHANICS

Spare Ratio (%)	Number of Mechanics[a]					
	3, 5	3, 6	3, 8	4, 5	4, 8	5, 5
11.4	N/A	.0174	.0080	.0127	.0015	.0135
20.5	N/A	.0073	.0002	.0065	.0008	.0007
29.5	N/A	.0001	.0001	.0020	.0002	.0012
40.9	N/A	.0006	.0000	.0000	.0000	.0000

NOTE: N/A = not applicable (base system)
[a] Evening and night shifts, morning shift.

TABLE 5 IMPACT OF REPAIR SCHEDULING POLICY

Spare Ratio (%)	Scheduling Policy	D	TISYS	LQU
11.4	FCFS	0.8780	6.91	2.60
	SPT	0.9420	5.56	1.70
	SPT+8 hrs. Wait Time	0.9250	5.70	1.83
	SPT+16 hrs. Wait Time	0.9580	5.49	1.67
	SPT+24 hrs. Wait Time	0.9280	5.64	1.74
20.5	FCFS	0.9565	6.61	1.79
	SPT	0.9880	5.77	1.82
	SPT+8 hrs. Wait Time	0.9771	5.86	1.84
	SPT+16 hrs. Wait Time	0.9868	5.61	1.87
	SPT+24 hrs. Wait Time	0.9769	5.92	1.89
29.5	FCFS	0.9819	6.63	2.44
	SPT	0.9962	5.46	1.70
	SPT+8 hrs. Wait Time	0.9966	5.52	1.72
	SPT+16 hrs. Wait Time	0.9976	5.78	1.82
	SPT+24 hrs. Wait Time	0.9940	6.01	1.97
40.9	FCFS	0.9953	6.55	2.34
	SPT	1.0000	5.37	1.60
	SPT+8 hrs. Wait Time	0.9996	5.69	1.76
	SPT+16 hrs. Wait Time	1.0000	5.42	1.62
	SPT+24 hrs. Wait Time	1.0000	5.39	1.62

perform better than random scheduling policies and that the application of the SPT rule with limits on the waiting time yields better results than those obtained with other rules. Because the current study indicates a significant advantage of SPT over FCFS and no significant difference between the SPT policy and any of its variations, it was decided to use SPT in all the remaining analyses.

Impact of Rates of Failure

Several factors can affect the rate of failure of individual bus components. These factors include age; environmental characteristics such as climate, terrain, and road conditions; and preventive maintenance policies followed by the system. Independent studies may be performed to estimate the effects of these factors on the rates of failure, but they can be costly and intractable. Alternatively, estimates may be obtained from experienced transit personnel. By adjusting the rate of failure of the individual components, the impact of these factors on the value of the spare ratio and on the overall system performance can be investigated.

The rates of failure observed for the system under consideration were assumed to be average. Two additional levels were investigated for the rates of failure, a higher level with 20 percent more failures and a lower level with 20 percent less. The results are given in Table 6 and in Figures 7, 8, and 9. As expected, all measures of performance demonstrated improvement with lower rates of failure and with higher spare ratios.

tem performance measures should hold true for most systems. These relationships provide valuable information to decision makers and to operators of bus transit systems. The model can also be modified to simulate the operations of different bus transit systems.

ACKNOWLEDGMENT

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Statistical Evaluation of Spare Ratio in Transit Rolling Stock

MAJID JARAIEDI AND WAFIK ISKANDER

In this paper, the results of a study of the problem of the spare ratio in the bus transit industry are examined. Statistical techniques were used to investigate the relationships between variations in spare ratio and characteristics of bus transit properties. Section 15 data for 1984 were used as the basis of the analysis. The use of cluster and discriminant analyses made it possible to specify 14 important variables that affect the spare ratio and use them collectively to classify properties into three groups, with high, average, or low spare ratios. It was determined that there is a significantly lower average total number of road calls per vehicle hour for properties that have a low spare ratio than there is for those that have medium or high ratios. Mechanical and total road calls per vehicle mile exhibit similar patterns. The percentage of federal assistance to total revenue has a lower average in systems with lower spare ratios, which means that properties that have high spare ratios have relied on federal assistance more than have those that have low spare ratios.

The rolling stock in public transit consists primarily of buses, light rail vehicles, and rapid transit cars used for carrying passengers. The majority of the vehicles in these fleets are dedicated to prescheduled service. To promote effective use of their resources, therefore, transit companies usually go to great lengths to ensure that the service they offer is available as advertised.

An aggregate ratio of the total number of active vehicles in a given fleet to the maximum number of vehicles scheduled on the street at any one time (during peak service) is referred to as the "spare ratio." The subject of this paper is the statistical evaluation of the spare ratio among bus operations and, more specifically, the exploration and identification of characteristics that are common to bus transit systems with similar, or close, spare ratios.

A great deal has been written about two closely related issues: bus maintenance and bus/vehicle replacement theory. Although these two subjects are closely related to the issue of spare vehicles, the latter topic has not been specifically addressed in the literature. An American Public Transit Association (APTA) working committee dealt with the issue of spare ratio and decided that the present across-the-board 120 guideline is not defensible. Instead, APTA has developed a rather complex formula for computing the spare ratio. In APTA's response to UMTA's proposed grant application requirements, it was concluded that "a single nationwide spare ratio guideline is inadequate to oversee the varying and complex circumstances affecting vehicle fleet management" (*1*).

DATA DESCRIPTION

A data base was constructed with information from more than 200 transit systems in the continental United States. Data for each property consisted of 58 variables, 43 of which were obtained from the 1984 Section 15 data (*2*). The first five variables provided information on the code, name, size, and location of each property. The next 38 variables were performance and status indicators reported by each property for 1984. Because it was postulated that climatic characteristics might also affect the maintenance operations of a transit property and hence the number of buses considered as spares, 15 additional variables were created to provide information on the climate in which each property operates. For a complete listing of all variables, refer to the report by Iskander and Jaraiedi (*3*).

STATISTICAL ANALYSIS

The first step in the statistical analysis of the data was computation of some simple descriptive statistics. The spare ratio ranged from 1.00 to 2.54 with a mean and a standard deviation of 1.30 and 0.23, respectively. Transit systems were placed into categories on the basis of the number of vehicles operated in maximum service. Descriptive statistics were computed for each category separately (Table 1). It can be observed that the number of vehicles in maximum service does not exhibit a significant effect on the mean or on other statistics of the spare ratio. The average spare ratio is somewhat higher for smaller systems.

Through regression analysis the relationship between spare ratio and the independent variables was also examined. A stepwise regression procedure with the objective of maximizing the coefficient of multiple determination, R^2, was used. For the model that includes the best 15 variables, R^2 was only 25 percent. Even after inclusion of all variables in the model, maximum R^2 increased to only 53 percent. Needless to say, inclusion of all these variables in a regression model is extremely inefficient, causes high variability in the coefficients, and reduces the prediction power of the model.

USE OF CLUSTER AND DISCRIMINANT ANALYSES

The objective of this analysis was to classify transit properties into categories with different values of spare ratio: high, average, and low. The first step involved the use of cluster analysis

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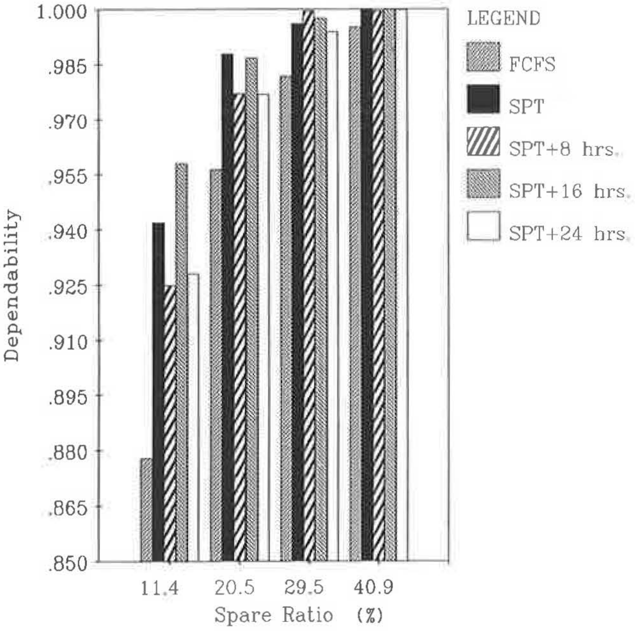

FIGURE 4 **Impact of repair scheduling policy on dependability.**

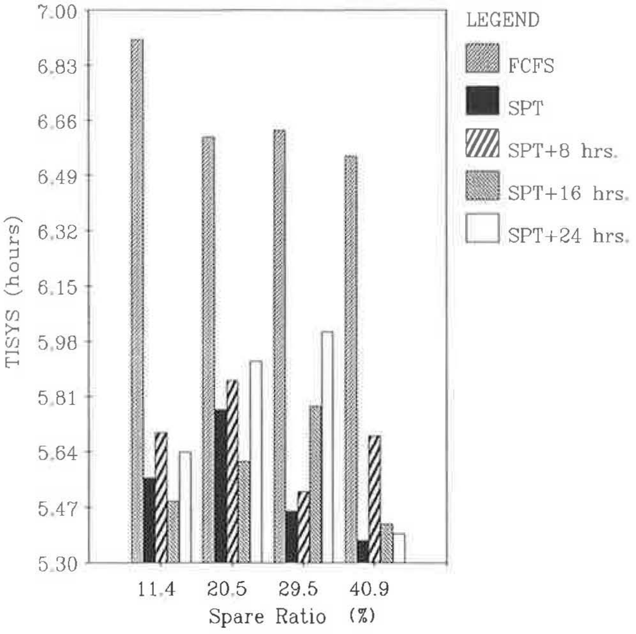

FIGURE 5 **Impact of repair scheduling policy on TISYS.**

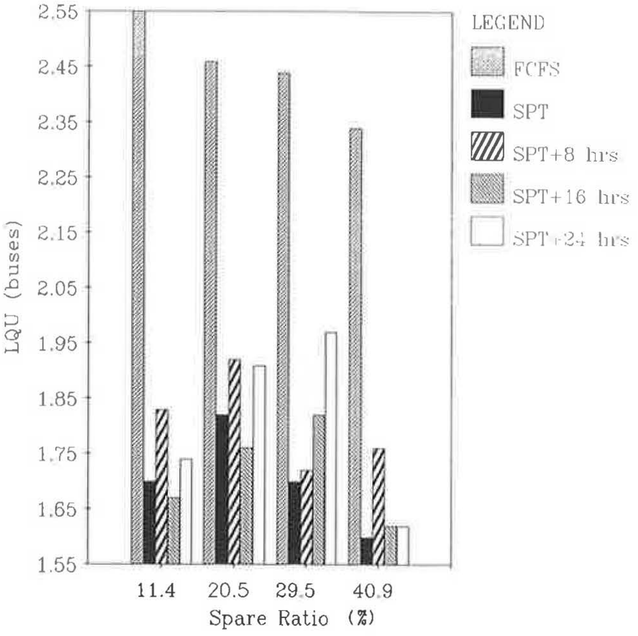

FIGURE 6 **Impact of repair scheduling policy on LQU.**

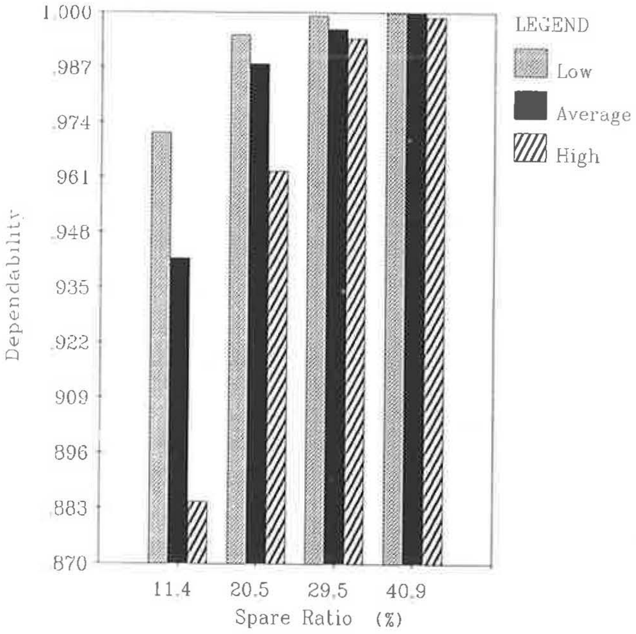

FIGURE 7 **Impact of rates of failure on dependability.**

TABLE 6 IMPACT OF RATES OF FAILURE

Spare ratio (%)	Rates of Failure	D	TISYS	LQU
11.4	Low	0.9716	5.13	1.18
	Average	0.9420	5.56	1.70
	High	0.8847	6.30	2.66
20.5	Low	0.9947	5.19	1.25
	Average	0.9880	5.77	1.82
	High	0.9626	6.35	2.70
29.5	Low	0.9994	5.14	1.21
	Average	0.9962	5.46	1.70
	High	0.9940	6.24	2.58
40.9	Low	1.0000	4.99	1.17
	Average	1.0000	5.37	1.60
	High	0.9994	5.99	2.38

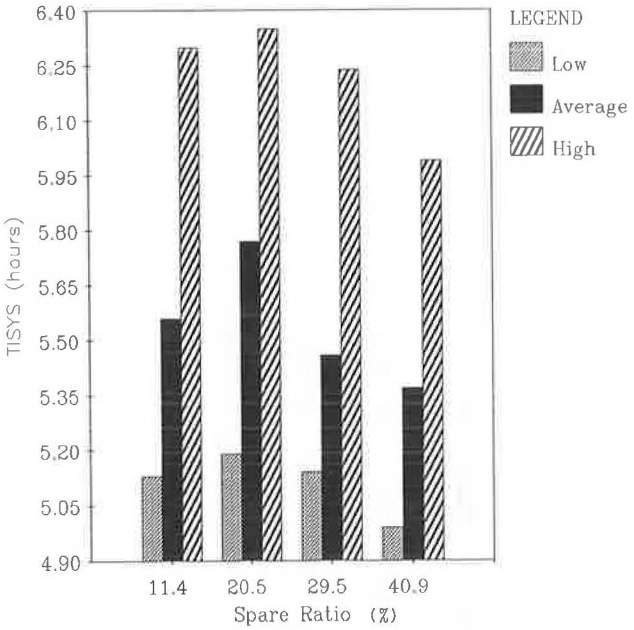

FIGURE 8 Impact of rates of failure on TISYS.

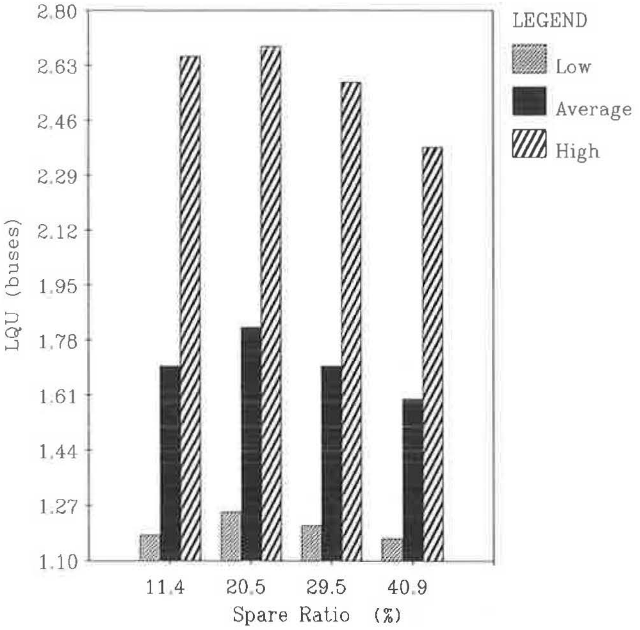

FIGURE 9 Impact of rates of failure on LQU.

CONCLUSION

A simulation model was developed to investigate proper choice of the spare ratio to maintain a desirable level of service dependability. The objective of the model was to study the effects of the time between bus breakdowns and the time to repair failed buses, as well as other characteristics of the system, on the value of the spare ratio and the overall performance of the transit system. The model was successfully validated and was used to simulate and study the operation of an existing bus transit system. The results are pertinent only to the system under consideration; however, the general relationships among spare ratios, number of mechanics, maintenance scheduling policies, rates of failure, and several sys-

TABLE 1 DESCRIPTIVE STATISTICS FOR THE SPARE RATIO BASED ON FLEET SIZE

Category Number	Number of Vehicles	Number in Category	Spare Ratio Mean	S.D.	Min	Max
1	> 1000	6	1.25	0.16	1.09	1.49
2	500–999	12	1.25	0.20	1.06	1.74
3	250–499	16	1.23	0.11	1.02	1.49
4	100–249	38	1.20	0.16	1.00	1.87
5	50–99	48	1.32	0.20	1.00	2.54
6	< 50	82	1.35	0.28	1.00	2.54
All systems combined		202	1.30	0.23	1.00	2.54

TABLE 2 SUMMARY OF CLUSTER ANALYSIS

Cluster	Frequency	Percent	Cumulative Frequency	Cluster Mean
1	81	40.9	81	1.12
2	79	39.2	160	1.30
3	38	19.2	198	1.59

procedures, which are commonly used to place observations into groups or clusters so that all observations placed in one group are similar to each other and different from observations placed in other clusters. Transit systems were clustered into three groups, according to their spare ratio value. Results of the analysis are summarized in Table 2.

The next step was a stepwise discriminant analysis, in which a subset of quantitative variables is selected to produce a good discrimination model. A significance level of 0.25 was used for entering or removing variables to or from the model. Before this analysis was performed, all observations had to be organized into three groups on the basis of the cluster analysis results. The boundaries between the three clusters were defined as 1.21 and 1.41, where a suitable breakdown in the spare ratios was observed. All systems for which the spare ratio was less than 1.21 were defined as having a low spare ratio and were placed in Group 1. Those with spare ratio between 1.21 and 1.41 were defined as having an average spare ratio and were placed in Group 2, and the rest were defined as having a high spare ratio and were classified in Group 3 (Table 3). This procedure identified seven key variables that have a significant correlation with spare ratio.

Because many statistical studies with empirical data demonstrate that the logarithmic transformation of variables tend to yield better results (in terms of alleviating deviation from normality), the same analysis was repeated with a model that contained both the independent variables and their natural logarithms. To accommodate the large number of variables in the data base, the significance level used for entering and removing variables was reduced to 0.15. This procedure resulted in the identification of 14 key variables, 9 of which were in the form of log transforms.

Linear discriminant functions were then produced by using these 14 variables. Each observation was then placed in one of the predetermined classes on the basis of its squared distance from the center of each class. Table 4 presents parts of the results obtained. Of the 71 properties that belong in Class 1, 45 (63 percent) were correctly classified in the same class. Of the 69 observations from Class 2, 52 (75 percent) were placed in the same class. For Class 3, 16 of the 33 observations were correctly classified. Overall, more than 65 percent of valid observations were correctly classified.

The average values of the key variables identified previously for the three classes of spare ratio (low, medium, high) and overall are presented in Table 5. The annual number of days with a temperature of 0° and below was significant both in its original and transformed forms, but only the original form is included in Table 5.

Examination of some of these variables provides interesting results. For example, the total number of road calls per vehicle hour (X_1) has a significantly lower average for properties with a low spare ratio than it does for those with medium or high ratios. The coefficient of simple correlation between the spare ratio and this variable is 0.161.

The second and third variables, which are mechanical and total road calls per vehicle mile, also exhibit the same pattern. Systems with low spare ratio have a considerably smaller average mechanical and total road calls than do other properties.

The percentage of federal assistance in total revenue (X_4) has a lower average for systems with lower spare ratios. This means that properties with high spare ratios have relied on federal assistance more than have those with lower spare ratios. It should be noted that the rate of increase with spare ratio for this variable is not significant.

An examination of variable X_5, the number of revenue

TABLE 3 STEPWISE DISCRIMINANT ANALYSIS SUMMARY OF RESULTS FOR ORIGINAL VARIABLES ONLY

Variable	*F* Stat.	Prob > *F*
Total vehicle mi/total employees	4.4	0.014
Annual passenger mi/vehicle revenue hr	4.1	0.019
Annual number of days 0° and below	4.3	0.016
Total mi/value of state and local assistance	2.4	0.094
Maintenance employees per total employees	2.2	0.110
Annual number of days above 90°	2.3	0.101
Revenue hr/value of state and local assistance	2.2	0.114

TABLE 4 CLASSIFICATION SUMMARY FOR THE SPARE RATIO: NUMBER OF OBSERVATIONS AND PERCENT CLASSIFIED

	To			
From	Low	Medium	High	Total
Low	45	17	9	71
	(63.38)	(23.94)	(12.68)	(100.00)
Medium	13	52	4	69
	(18.84)	(75.36)	(5.80)	(100.00)
High	8	9	16	33
	(24.24)	(27.27)	(48.48)	(100.00)
Total	66	78	29	173
	(38.15)	(45.09)	(16.76)	(100.00)

NOTE: Percent classified in parentheses.

TABLE 5 AVERAGE VALUES FOR ALL IMPORTANT VARIABLES FOR EACH SPARE RATIO CLASS

		Spare Ratio			
Variable	Definition	Low	Medium	High	Overall
X_1	Total road calls/vehicle hr	4.6	6.4	6.9	5.7
X_2	Mechanical road calls/vehicle mi	27.2	35.1	37.5	32.3
X_3	Total road calls/vehicle mi	35.4	51.4	52.4	45.0
X_4	Percentage of federal assistance in total revenue	19.4	20.1	22.2	20.2
X_5	Revenue mi/value of total federal assistance	576.1	181.2	197.0	345.9
X_6	Total mi/value of state and local investment	155.6	151.9	782.3	273.7
X_7	Operating expenses per vehicle in maximum service ($1,000)	109.8	107.3	115.7	110.0
X_8	Revenue mechanics per total no. of maintenance employees	56.1	53.8	50.0	54.1
X_9	Total vehicle mi per total employees	15.3	14.0	15.1	14.7
X_{10}	Annual number of days below 32° (freezing)	87.9	81.2	81.9	84.1
X_{11}	Annual number of days 0° and below	6.3	3.6	4.0	4.8
X_{12}	Annual passenger mi per 1,000 directional mi	136.4	96.9	108.0	115.5
X_{13}	Annual passenger mi per vehicle revenue hr	149.5	118.4	120.0	131.7

miles per total dollar value of federal assistance, reveals that systems with low spare ratios have a much higher average value for this variable. In other words, having a higher number of *revenue miles* per federal dollar puts a property in a stronger position to maintain a low spare ratio. Similar arguments can be made for variables X_6, X_{12}, and X_{13}.

CONCLUSIONS

Multivariate statistical analysis demonstrates that only a few of the variables that characterize a bus transit system exhibit a statistically significant correlation with spare ratio. Cluster and discriminant analyses were used to specify 14 important variables that affect spare ratio. These variables were used collectively to classify transit systems in three groups with high, average, and low spare ratios.

It was demonstrated that the average total number of road calls per vehicle hour is significantly lower for properties with low spare ratios than it is for those with medium or high spare ratios. Mechanical and total road calls per vehicle mile exhibited the same pattern. Systems with low spare ratios have much smaller average mechanical and total road calls than do other properties. The correlation coefficient between the spare ratio and these variables are positive.

The percentage of federal assistance to total revenue also has a lower average for systems with lower spare ratios. For some properties, however, this result may not prove valid because the level of federal subsidy reported in Section 15 does not specify subsidy by mode. Systems with low spare ratios also have a much higher average value for the number of revenue miles per total dollar value of federal assistance.

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