TRANSPORTATION RESEARCH

RECORD

No. 1349

Public Transit

Public Transit: Management, Operations, and Planning and Development

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1992

Transportation Research Record 1349
Price: $26.00

Subscriber Category
VI public transit

TRB Publications Staff
Director of Reports and Editorial Services: Nancy A. Ackerman
Senior Editor: Naomi C. Kassabian
Associate Editor: Alison G. Tobias
Assistant Editors: Luanne Crayton, Norman Solomon, Susan E. Gober
Office Manager: Phyllis D. Barber
Production Assistant: Betty L. Hawkins

Printed in the United States of America

Library of Congress Cataloging-in-Publication Data
National Research Council. Transportation Research Board.

Public transit : management, operations planning, and development.
p. cm.—(Transportation research record, ISSN 0361-1981 ; no. 1349)
"A peer-reviewed publication of the Transportation Research Board."
ISBN 0-309-05212-2
1. Urban transportation—United States—Management. 2. Urban transportation—United States—Planning. 3. Local transit—United States—Management. 4. Local transit—United States—Planning. I. National Research Council (U.S.). Transportation Research Board. II. Series.
TH7.H5 1992
[HE308]
388 s—dc20 92-26084
[388.4'068] CIP

Sponsorship of Transportation Research Record 1349

GROUP 1—TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Chairman: Sally Hill Cooper, Virginia Department of Transportation

Public Transportation Section
Chairman: James C. Echols, Tidewater Regional Transit

Committee on Public Transportation Planning and Development
Chairman: Michael A. Kemp, Charles River Associates, Inc.
Vice-Chairman: Patricia V. McLaughlin, Los Angeles County Transportation Commission
Secretary: David R. Miller, Parsons Brinckerhoff et al.
Paul J. Ballard, Linda Bohlinger, Anne P. Canby, Chester E. Colby, Stephen Gordon, George E. Gray, S. Olof Gunnarsson, Brendon Hemily, Nathan L. Jaschik, Hermann Knoflacher, Daniel R. Leffers, Perry J. Maull, Robert L. Peskin, Patti Post, James P. Redeker, Jacques P. Roulet, Dennis H. Ryan, George M. Smerk, Samuel L. Zimmerman

Committee on Intermodal Transfer Facilities
Chairman: John S. Pavlovich, Edwards and Kelcey, Inc.
Secretary: Gregory P. Benz, Parsons Brinckerhoff et al.
Charles F. Arndt, Howard P. Benn, John P. Braaksma, Donald L. Dean, Benita H. Gray, Thomas R. Hickey, Barry J. Kaas, Adib Kanafani, Jerome M. Lutin, Richard R. Sarles, Joerg Schoenharting

Committee on Rail Transit Systems
Chairman: Robert J. Landgraf, Shaker Heights, Ohio
Secretary: S. David Phraner, Port Authority of New York and New Jersey
John A. Bailey, John J. Bakker, J. W. Boorse, Glen D. Bottoms, Peter Fahrenwald, Alex E. Friedlander, Howard L. Goode, Wendy J. Hoyt, Daniel L. Jones, Jr., Ata M. Khan, Thomas F. Larwin, R. David Minister, David J. Mitchell, Steven E. Polzin, P. Takis Salpeas, Peter J. Schmidt, John W. Schumann, Richard Miller Stanger, Vukan R. Vuchic

Committee on Transit Management and Performance
Chairman: Littleton C. MacDorman, MacDorman & Associates Inc.
Colin H. Alter, H. Scott Baker, Darold T. Barnum, A. Jeff Becker, Douglas W. Carter, Susan G. Clark, John A. Cline, Ronald J. Fisher, Dennis J. Fitzgerald, Gerald T. Haugh, Louisa Ho, David A. Lee, William M. Lyons, Joel E. Markowitz, Roy Nakadegawa, Sharon Neely, Lynn Ritter Otte, Steven Silkunas, Cheryl Y. Spicer, Nigel H. M. Wilson, Eve Morton Wyatt

Committee on Commuter Rail Transportation
Chairman: Donald O. Eisele, New Jersey Transit
Vice Chairman: Emmanuel S. Horowitz, AMTRAK
James W. Burcham, George E. Gray, Jack M. Kanarek, Eugene K. Skoropowski, James Stoetzel, Edson L. Tennyson, John F. Tucker III, Walter E. Zullig, Jr.

Committee on New Transportation Systems and Technology
Chairman: Thomas J.McGean, Lea Elliott McGean & Co.
Murthy V. A. Bondada, Daniel Brand, Salvatore Castronovo, Ovi M. S. Colavincenzo, G. Bruce Douglas III, Samy E. G. Elias, Lawrence J. Fabian, Franz K. Gimmler, Shinya Kikuchi, Rolland D. King, Richard M. Michaels, Edward S. Neumann, Danilo J. Santini, Louis A. Schmitt, Albert J. Sobey, Joseph M. Sussman, Joe Tsai

Wm. Campbell Graeub, Transportation Research Board staff

Sponsorship is indicated by a footnote at the end of each paper. The organizational units, officers, and members are as of December 31, 1991.

Transportation Research Record 1349

Contents

Foreword

This Record contains 18 papers in the general area of transit management, operations, and planning and development. Part 1 deals with the larger issues of management and transit performance. It reports on the service quality of high-frequency transit lines, the experience with the accuracy and reliability of random drug and alcohol testing, an evaluation of the Section 15 Uniform System of Accounts and Records and Reporting System, and an investigation of the ability of the federally required cost-effectiveness index to serve as a desirable selection criterion for rail-transit projects.

Part 2 reports on studies in the areas of transit operations and operations planning. The topics include a method used for measuring transfer times between transit routes, a feasibility study of transit improvements between Queens and Manhattan, and a method for estimating passenger origin-destination of a transit line so that passenger volumes for selected station pairs can be determined. A summary of North American commuter rail operations and a feasibility study for providing child care at transit stations aimed at learning how such service could increase transit ridership are also presented.

Part 3 covers various topics in the area of transit planning and development. The results of privatizing transit services continue to be studied. Denver's first-year experience in privatizing transit services is reported, as are the effects of a transit agency's initiative for privately operated services on access to jobs. Farkas examines the factors of reverse commuting, the travel of inner-city urban dwellers to commute to suburban jobs, and the opportunities for transit operators to provide such services. A study of a frequently overlooked travel need, the midday transit use of downtown workers, is also presented.

Part 3 also discusses planning activities and transit services. The nature of land use patterns that are sensitive to the needs of public transit, a survey of organizations across 30 states on their use of geographic information systems, and the importance of public transportation in the New York metropolitan region and requirements to meet the demand that must be satisfied by the year 2015 are presented.

The last two papers in Part 3 address new transportation technologies. The first paper discusses the features and application potential of various cable-propelled people mover systems for urban environments and the last chronicles the development of a personal rapid transit project planned for a suburban area outside Chicago, which should serve as a test of its feasibility in a low-density setting.

PART 1

Management

Service-Quality Monitoring for High-Frequency Transit Lines

NIGEL H. M. WILSON, DAVID NELSON, ANTHONY PALMERE, THOMAS H. GRAYSON, AND CARL CEDERQUIST

Over the past 2 years the Massachusetts Bay Transportation Authority (MBTA) has been developing ways to monitor service quality on high-frequency rail transit lines. The approaches taken to measuring service quality and displaying relevant information in real time to system controllers who have the responsibility to take ameliorative action are discussed. The resulting system has been implemented for the rail rapid transit and light rail lines of MBTA, focusing on accurately monitoring the passenger waiting time at key points in the network. This approach is particularly attractive for older rail systems and high-frequency bus lines that are not equipped with automatic vehicle location (AVL) systems and may also be extended to form a comprehensive service-quality monitoring system when AVL systems are installed.

The problem of monitoring service quality on high-frequency transit lines and a system that has been developed and implemented at the Massachusetts Bay Transportation Authority (MBTA) over the past 2 years are described. The aim of this paper is to show how, even in old transit systems that are heavily constrained in terms of capital and new technology, systems can be developed that effectively measure (in real time) important components of service quality. As it exists now, the MBTA system is limited to monitoring headways at critical points on the rail transit lines. As newer and more reliable automatic vehicle identification (AVI) and automatic vehicle location (AVL) systems are introduced, the scope of the service-quality monitoring system can be expanded.

The general problem of service-quality measurement on high-frequency transit lines is also discussed emphasizing passenger waiting time. Subsequently, the focus is on the MBTA system, with a description of the hardware and software currently in use, and presentation of the results of the monitoring process. Finally, there is a brief discussion of the potential for expansion of this type of service-quality monitoring system.

SERVICE-QUALITY MONITORING

Monitoring transit service quality is important in at least three respects. First, as part of operations control, monitoring service in real time is the essential basis for dealing with incipient problems before they become serious. For this it is necessary to capture and display relevant information in a form that a controller can readily assimilate and respond to. Second, it is necessary to record significant incidents that harm service quality so that they can be investigated and, where possible, steps can be taken to prevent their recurrence. Third, it is important to measure service quality over time so that the results of changes in the operations plan or in operations control procedures can be measured. Such service-quality measures can also be used for setting annual objectives and for reporting to governance and oversight boards.

Service quality has many dimensions, some of which depend on the design of the service and others, on operational performance. For example, number of transfers required, access distance and time, and fare are all facets of service quality, that are determined by service design (*1*). Other aspects such as waiting time, riding time, reliability, and comfort are affected by actual operations and by the service design (*2*). In this paper we are most interested in these latter aspects of service quality because they should be more amenable to improvement in the short run without major capital investments or planning initiatives.

It is also likely to be less expensive and more efficient to focus on measures of service quality that are based on vehicle observations (and passenger counts) rather than on passenger interviews. It is certainly possible to obtain richer information on service quality through passenger interviews, but it is not a realistic basis for a continuous service-quality monitoring program. However, it is important to undertake passenger surveys periodically to ensure that the proxy measures being used daily are consistent with true passenger perceptions of service quality. Measuring service quality using data that principally rely on observations of vehicles makes it difficult to estimate service quality for individual passengers, but this is not the real aim of such a monitoring system. Realistic aims might be

- To measure average service quality,
- To compare actual service quality with an ideal standard, and
- To measure the percentage of passengers receiving good (and bad) service.

All of these are possible for one or more aspects of service quality, provided at least one of the following automated detection systems is in use: automatic vehicle detection (AVD), AVI, or automatic passenger counters (APCs). Service-quality measures could also be based on manual data collec-

N. H. M. Wilson and T. H. Grayson, Department of Civil Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Mass. 02319. D. Nelson, A. Palmere, and C. Cederquist, Massachusetts Bay Transportation Authority, 10 Park Plaza, Boston, Mass. 02116.

tion techniques, such as point checks on a high-frequency bus route, but the objective of monitoring system performance in real time requires automated vehicle monitoring. Each of these three approaches to automated monitoring is discussed with the corresponding facets of service quality that can be measured.

Automatic Vehicle Detection

An AVD system is the minimal basis for doing any automated service-quality monitoring and severely limits what can be monitored. Such a system simply registers the passage of a vehicle at a point in the network and transmits this signal to the control center for processing, but it provides no identification or other information on the vehicle. Thus, although headways at detection points can be deduced, there is no ability to determine travel time for a particular vehicle between detectors on a line. AVD systems exist on many older rail networks, such as MBTA's, but they would never be installed as new technology because AVI systems provide better information for essentially the same cost. For AVD-equipped systems, information is available on individual headways. This information can be used to estimate expected (average) passenger waiting time at detector locations. This process will be explored in the context of the MBTA system later.

Automatic Vehicle Identification

AVI systems provide a unique vehicle identifier and detection. A distinction might be made between AVI technology, defined as providing vehicle passage times at selected points within the network, and AVL systems, which provide more continuous information on vehicle locations (*3*). This distinction might be important in some aspects of real-time control (i.e., in an emergency response situation) but for many other aspects of operations control and for service-quality monitoring it is less important. Specifically, real-time operations-control actions are likely to be appropriate only at limited points in the network and service-quality measures must also be aggregated in some way to be meaningful.

With AVI data it is possible to measure travel times between points on the service network and estimate waiting times at specific points. However, with AVI it is still not possible to measure directly anything related to passenger crowding on board vehicles. For this purpose, APC systems are also required.

Automatic Passenger Counters

APC systems provide counts of passengers on board vehicles at any point on a route (*4*). To date, APC systems have been used for off-line planning and scheduling purposes rather than as part of a real-time operations control system. However, there is potential to integrate APCs into AVI (AVL) systems to provide passenger load information in real time. Clearly, there would be significant additional costs in this because all of the vehicles would have to be APC-equipped, rather than just a sample of about 10 percent, which is currently the rule for APC systems used to support operations planning. Two alternatives exist, and they still retain some of the benefits of having passenger count information. First, the vehicle operator could be asked to input approximate passenger load information manually. This approach is used at the Toronto Transit Commission (TTC) to provide real-time load data for its comprehensive bus service monitoring system. Second, the central computer could estimate passenger loads on the basis of real-time headway data and information on passenger flow rates. This method is used at San Francisco Bay Area Rapid Transit (BART), for example, where complete data are provided on passenger entries and exits, as well as train arrivals and departures by clock time for every station.

The main advantage of APC-type data is that passenger load–related information can be incorporated into service-quality monitoring. Such measures could include standing and crush load conditions and estimates of denied passenger boardings.

Waiting-Time Measures for High-Frequency Transit Lines

The focus here is service quality on high-frequency transit services, which will be defined to have mean headways of 10 min or less. This frequency is characteristic of most urban rail systems and many bus routes in the inner portions of major cities, particularly in peak periods. On these short headway routes, it is generally assumed that passengers arrive at transit stops independent of the timetable. At longer headways, of course, an increasing proportion of passengers arrive at stops at times designed on the timetable to minimize their expected wait, that is, they try to arrive just before the transit vehicle arrives (*5*). In the latter case good service quality will usually be achieved by improving on-time performance—by minimizing the difference between scheduled and actual vehicle arrival times (but avoiding early arrivals)—but this is less appropriate for high-frequency service. Abkowitz et al. and Henderson et al. (*2,6*) provide good reviews of service quality indexes for high-frequency transit services.

For randomly arriving passengers at a constant mean arrival rate, it has been shown (*5,7*) that the expected passenger waiting time is given by

$$\bar{w} = \frac{\bar{h}}{2}[1 + \text{cov}^2(h)] \qquad (1)$$

where

$\bar{w}$ = mean passenger waiting time,
$\bar{h}$ = mean headway, and
$\text{cov}(h)$ = coefficient of variation of headway, that is, standard deviation divided by mean headway.

If all headways are identical, $\text{cov}(h) = 0$ and the mean wait time is simply half the mean headway, but as the standard deviation of headway increases, so does the mean passenger waiting time.

Equation 1 provides a simple and direct means to estimate passenger wait times given only AVD data. It must be stated that this is predicted on an assumed constant average rate of passenger arrivals—which will seldom be the case; but even with somewhat variable passenger arrival rates, this measure is likely to be a reasonably good representation of mean passenger waiting time. To account for highly variable passenger arrival rates, a better estimate could be obtained by using prior data on average passenger arrival rates in Equation 2.

$$\overline{w_p} = \frac{1}{2} \sum_{i=1}^{n} h_i^2 \times p_i \Big/ \sum_{i=1}^{n} h_i \times p_i \qquad (2)$$

where

$\overline{w_p}$ = mean (passenger-weighted) passenger waiting time,
h_i = headway of ith vehicle, for each of n consecutive vehicle trips, and
p_i = mean passenger arrival rate during h_i.

Theoretically $\overline{w_p}$ is a better measure of passenger waiting time for the average passenger, but it depends on having reasonably accurate data on passenger arrival rates over small time intervals. For the MBTA system and other older rail systems, current data of this type are unlikely to be available, and therefore Equation 1 with an assumed constant passenger arrival rate will be used for this analysis. To minimize errors associated with this assumption, time periods used for computing passenger wait time should be small (i.e., a peak period rather than a complete day).

Two other types of measure are useful supplements to the mean passenger waiting time: excess passenger wait time and passenger wait time percentages. Excess passenger wait time has been used by London Transport to capture service reliability and it is useful for comparing service quality across routes with quite different headways (*8*). It is the difference between the actual expected wait time and the expected wait time that would result if there were perfect schedule adherence. Thus, excess passenger wait time is given by

$$EWT = \overline{w} - \frac{\overline{h_s}}{2}[1 + \text{cov}^2(h_s)] \qquad (3)$$

where

EWT = excess passenger wait time,
$\overline{h_s}$ = mean scheduled headway, and
$\text{cov}(h_s)$ = coefficient of variation of scheduled headway.

For any period in which the scheduled headway is constant, *EWT* is simply the mean passenger waiting time minus half the scheduled headway. In some cases, particularly for longer periods, the scheduled headway will vary and thus the coefficient of variation for scheduled headway will be nonzero.

Finally, it would be valuable to measure the portion of passengers who receive good (and bad) service using passenger wait time percentages. In a high-frequency service with randomly arriving passengers, ideally everyone would be served within a maximum wait of one scheduled headway. This can be approximated by the total time within one scheduled headway of a vehicle arrival, expressed as a percentage of the total time. This should be as close to 100 percent as possible. At the other end of the spectrum, bad service may be defined as the total time for which the next vehicle arrival is more than two scheduled headways away, again expressed as a percentage of the total time. Ideally this percentage should be zero.

These three measures provide a concise, but comprehensive, characterization of passenger waiting time within the constraints of an AVD-type detection system.

MBTA SERVICE-QUALITY MONITORING SYSTEM

MBTA is responsible for the delivery of public transportation services for metropolitan Boston, which encompasses 78 cities and towns. MBTA offers bus, light rail, heavy rail, commuter rail, commuter boat, and paratransit service for a daily ridership of 650,000 passengers. More than 60 percent of these passengers are served by urban rail transit, which consists of the Green, Red, Orange, and Blue lines. The Green Line is a four-branch, low-platform, overhead catenary, light rail system that operates as streetcars in mixed traffic and on exclusive rights-of-way on some surface branches and also in the common downtown subway. The Red, Orange, and Blue lines are all high-platform, third-rail rapid transit operations.

The signal and control systems vary enormously among these rail lines:

- The Green Line has an absolute block signal (ABS) system. All interlockings are controlled by vehicle operators as they approach the switch and call their route. There is no centralized signal control and only a rudimentary monitoring capability. An AVI system is now being installed that will automate the route selection function and provide more information to the control center in real time.
- The Red Line is centrally dispatched by a controller working with three tower persons in the control center. The line uses ABS traffic control rules and relies on automatic train operation (ATO) for speed control. There is a rudimentary and obsolete AVI system on the Red Line.
- The Orange Line uses centralized traffic control rules and is controlled by a dispatcher at the control center who works with a towerman at the maintenance yard. There is an ATO system that exercises speed-control functions and a very limited AVI system.
- The Blue Line is an ABS system with interlockings controlled from a tower at the maintenance and storage facility. There are no Blue Line monitoring or control facilities in the control center.

With such a mix of signal and control systems there has been no easy way to monitor, manage, and measure performance of the rail transit lines on a common basis.

Historical Context

Traditionally, operations effectiveness was measured with a software application known as Thruput, which compared the actual and scheduled numbers of trains passing detectors during half-hour periods. All data were hand-entered into the computer at half-hour intervals. Thruput provided an estimate of the quantity of service provided at each location but was not sensitive to the distribution of trains over each half-hour interval, and therefore did not reflect the passenger's perception of service quality.

The new Passenger Waiting Time application was designed to allow for more detailed measurement and rigorous analysis of schedule adherence from the Thruput locations by recording the actual times that trains passed these points and comparing actual and scheduled headways. As train detection signals are received, the system performs three functions:

- Maintains a real-time monitor showing system status (last train observed, next train due, delay status, Thruput tally) at each location;
- Prepares half-hourly reports showing all significant delays and the Thruput counts for each period; and
- Calculates periodic service-quality summary statistics.

The Passenger Waiting Time system is a set of computer programs that run on a PC-DOS local area network (LAN) supported by a programmable controller (a UMAC) that monitors the field detectors. The system logs the passage of trains by each detector and provides a continuous real-time color-coded display of scheduled versus actual performance at each location. Each half-hour the system produces a report showing significant delays detected and the Thruput tally for each location. At the end of each rush hour and each day, standard reports summarize passenger service-quality measures. The overall system architecture is shown in Figure 1; each of the critical elements is described briefly.

Automatic Vehicle Detection

Figure 2 shows the MBTA rail network with the 29 detector locations marked. The 13 Green Line detectors are suspended from the catenary and activated by each car's pantograph, and 16 rapid transit detectors are wired to signal block relays that indicate track occupancy. Each detector is linked to a separate input port on the programmable controller in the control center. The controller has a 64K microprocessor that runs a simple BASIC program in a continuous loop, polling the input ports and posting any observations to an output array with port identifier and the exact time of the observation.

Real-Time Monitor

The controller is polled every 12 sec by the application program that runs on an IBM PS/2 Model 55SX. The real-time monitor then

- Posts new observations to a data file for later batch reporting;
- Compares the latest observations for each detector with a headway schedule array to detect operating anomalies (trains too close together or too far apart);
- Updates its screen output arrays to show new observations; and
- Refreshes its screen display to reflect new data received and the progress of already-identified delays (see Figure 3).

The video display is modeled after an airport arrivals-and-departures board and is color-coded to reflect the colors of MBTA's four rail transit lines. Conditions such as delays and trains following too closely (hot) are flagged and highlighted. When a train is 2 min overdue, a message indicating this delay is displayed for that location. As passengers continue to wait, the delay message is incremented. If the delay grows to 10 min the affected portion of the display flashes until the delay is alleviated.

Auxiliary Monitors

The real-time monitor drives a series of auxiliary monitors in the control center as follows

- 13-in. monitors are in each dispatcher's work area, in the public address announcer's cubicle, and in the office of the superintendent of the control center.
- 26-in. monitors are suspended from the ceiling in the control center, oriented so that one is visible from any location in the room.

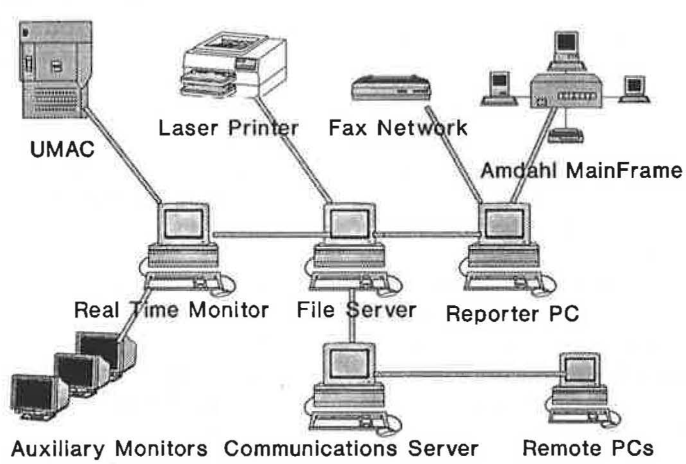


FIGURE 1 System architecture.

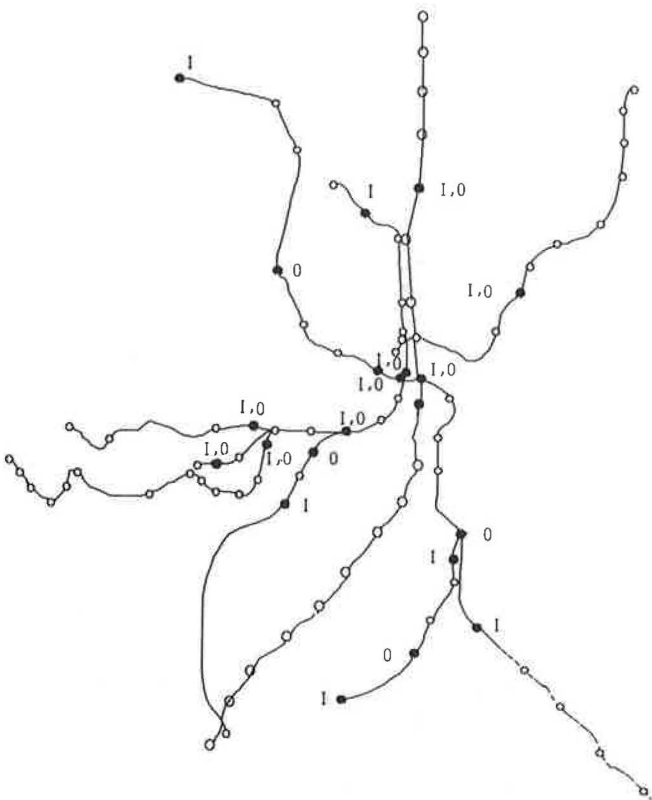


FIGURE 2 MBTA rail detector map.

The auxiliary monitors are used to identify delays, guide disruption relief work (announcements, extra trains, short turns, etc.), and monitor service conditions. There is also a dedicated direct line between the control center and the headquarters of the MBTA Transportation Department in another building in downtown Boston. The transportation department's remote node drives three additional auxiliary monitors that monitor system status.

When the new Green Line AVI system is fully operational, this new input will replace the obsolete detectors currently in use.

Data Reporting

In a typical weekday the system processes more than 7,000 observations from the field detectors. Two types of report have been developed to summarize these data for management and performance monitoring: operating reports are used by transit operating staff to provide operating statistics and highlight anomalies (delays) for review or investigation, and summary reports are used by planners, senior executives, and external constituencies to summarize customer service statistics.

Operating Reports

Every half-hour a report is printed showing Thruput performance for the last period and the previous six periods (see Figure 4). As noted previously, the Thruput measure simply compares the number of trains passing a detector to the number scheduled within that half-hour period. The Thruput component facilitates the transition from the old performance measurement system to the new system and it also lists all delays greater than 5 min that have occurred in the last half-hour.

Every half-hour there is an automatic upload of all trips and delays observed to the MBTA's mainframe on-line system. Each delay has a cause coded by the controller to facilitate subsequent investigation and reporting. A series of on-line reports on the trip and delay data are available when users specify their own data selection and sorting criteria. Reports are printed in users' offices at field locations.

In addition to the mainframe facilities, a fax board is integrated into the LAN for the distribution of reports. This

Massachusetts Bay Transportation Authority
Passenger Waiting Time Monitoring System
08:54:49

Monday 02-18-1991
Service Type SAT

INBOUND						OUTBOUND					
Location	Thruput Sch	Act	Last Trip	Next Trip		Location	Thruput Sch	Act	Last Trip	Next Trip	
No Quincy	2	2	8:41	8:54		JFK/Brntre	2	2	8:51	9:04	
Savin Hill	2	2	8:50	9:03		JFK/Ashmnt	2	2	8:47	9:00	
Downtown	4	4	8:54	9:00		Downtown	4	4	8:52	8:59	
Charles St	5	3	8:49	8:56		**Charles St**	**5**	**3**	**8:42**	**8:50**	**D>5**
Alewife	4	3	8:48	8:54		**Harvard**	**4**	**3**	**8:41**	**8:49**	**D>6**
Maverick	**4**	**5**	**8:53**	**9:00**	**HOT**	Maverick	4	5	8:49	8:57	
Mattapan	3	3	8:48	9:00		Ashmont	4	2	8:46	8:54	
Fenway	4	2	8:52	9:02		Fenway	3	2	8:45	8:55	
St Marys	4	3	8:49	8:57		St Marys	3	2	8:52	9:02	
Blandford	4	3	8:46	8:53		Blandford	4	5	8:52	8:59	
Northeastn	3	3	8:51	9:01		Prudential	3	2	8:45	8:55	
Arlington	14	12	8:54	8:55		Arlington	14	11	8:43	8:54	
Science Pk	3	3	8:51	9:01							
Chinatown	3	2	8:50	9:00		Chinatown	3	2	8:51	9:02	
Community	2	2	8:53	9:04		Community	2	2	8:45	8:57	

FIGURE 3 Real-time monitor sample display.

Massachusetts Bay Transportation Authority FRI 02-29-1991
Passenger Waiting Time Monitoring System 12:30:12
Half Hourly Thruput & Delay Report

INBOUND

	Period Starting: 12:00				Previous Variances					
Location	Sch	Act	Var	Pct	11:30	11:00	10:30	10:00	9:30	9:00
Maverick	4	3	-1	75	1	0	-1	0	1	0
Arborway	6	4	-2	66	1	1	0	0	0	0
Boston Col	6	6	0	100	0	0	2	-1	-1	0
Cleveland	6	5	-1	83	0	0	0	0	0	0
Green Core	24	19	-5	79	2	3	0	1	-2	3
Lechmere	6	5	-1	66	0	0	0	0	0	0
Mattapan	4	4	0	100	0	1	-1	0	0	0
Riverside	6	5	-1	83	0	-1	0	-1	0	0
Forest Hls	4	4	0	100	0	0	0	0	0	0
Oak Grove	4	3	-1	75	1	0	1	-1	0	0
Ashmont	3	3	0	100	0	0	0	0	0	0
Braintree	2	2	0	100	0	0	0	0	0	0
Alewife	5	5	0	100	0	0	0	0	0	0
Portal Bea	5	5	0	100	0	0	0	0	0	0
Downtown	5	5	0	100	0	0	-2	+1	+1	-2

FIGURE 4 Sample half-hour report.

facility is used to send the half-hour delay and Thruput summary to the chief transportation officer. Daily delay reports are automatically compiled and faxed to district offices each night at the close of service.

Currently, the supervisors of the light rail lines systematically investigate all delays of more than 10 min. Reports are targeted to reflect the scope of individual inspectors' service areas and duty hours, and it appears this program is working effectively to reduce long delays on the Green Line.

Summary Reports

The summary reports differ radically from the operating reports in that they statistically abstract the operating data to serve as proxies for the customer's perspective on the service. Summary reports are prepared three times a day: 8:30 a.m. (for morning peak period), 5:30 p.m. (for afternoon peak period), and 1:30 a.m. (for the complete day). The same statistics are presented in each of these reports; only the reporting period and format differ. For each branch of the four rail lines, the three statistics introduced in the earlier section on service-quality monitoring are computed and displayed for the two peak periods and the full day. These statistics—mean passenger wait time, excess passenger wait time, and passenger wait time percentages—provide a sufficient level of detail to assess the day's service. The summary sheet of the daily performance report is shown in Figure 5. The example day shows fairly typical service, with the exception of the Orange Line afternoon peak.

Summary statistics are distributed automatically by fax; they are also available on the mainframe in an on-line database used for rapid retrieval, ad hoc reporting, trend analyses, and archival purposes. The trend analysis not only provides data on whether passenger wait times are improving or declining, but it also provides a sense of scale to measure an individual day's performance. Figure 6 shows examples of trend analysis for the passenger wait time percentages and excess wait time for the Orange Line in the p.m. peak period for FY 1991.

Limitations of Existing System

The new rail service monitoring system makes use of existing operational data but summarizes it in a statistical form that approximates the customer's perspective (wait time) instead of the operator's (Thruput). This system is a major advance over the previous Thruput system, but it is still subject to some important limitations and incorporates several key assumptions. Probably the most significant limitation is that it measures only the passenger waiting time aspect of service quality, which is certainly one of the most important components of service quality but not the only one. As is discussed in the following section, implementing an AVI system to replace the AVD system will allow other facets of service quality to be monitored.

Given this limitation, several other assumptions are required for the service-quality measures to be accurate:

1. All trains detected are in normal revenue service. Trains that are dead-heading out of service because of mechanical problems or in express service will also be detected just as any train in normal revenue service. However, passengers will be unable to board them because they will pass through the station without stopping.
2. Enough space is always available on board any train to accommodate anyone waiting for service (i.e., there are no denied boardings).
3. Any passenger waiting at a station can board any train, regardless of final destination. This does not account for branching network structures and short-run trips, both of which exist in the MBTA rail system.

Violation of any of these assumptions means that the waiting time measures will underestimate true passenger waiting

Massachusetts Bay Transportation Authority
Daily Passenger Waiting Time Summary
2 6 91

PEAK PERIOD

AM Inbound Sched Hdwy	Obsrvd Wait	Excess Wait	% Psgr Waiting < 1 Hdwy	> 2 Hdwy	Line	Branch	PM Outbound Sched Hdwy	Obsrvd Wait	Excess Wait	% Psgr Waiting < 1 Hdwy	> 2 Hdwy
8:34	4:31	0:09	90.6		Red	Braintree	8:34	4:24	0:00	88.6	
8:31	4:25	0:03	94.0		Red	Ashmont	8:38	4:53	0:27	86.7	
4:22	2:33	0:18	85.4		Red	Alewife	4:16	2:42	0:31	81.4	2.6
4:46	2:44	0:21	85.5	1	Org	Oak Grove	5:18	4:42	1:54	75.3	11.5
5:07	3:03	0:23	86.5	1	Org	Forest Hls	5:18	4:29	1:39	70.7	11
3:30	2:18	0:24	86.3	0.2	Blu	All Service	3:23	2:16	0:21	85.4	0.2
5:11	3:34	0:53	81.7	5.9	Grn	Boston Col	5:20	3:37	0:49	81.6	3.7
6:04	3:07	0:00	92.5		Grn	Cleveland	5:57	3:43	0:42	82.2	1.6
3:28	2:31	0:47	72.0	4.3	Grn	Riverside	4:05	3:44	1:41	60.5	9.4
8:42	4:37	0:09	91.7		Grn	Arborway	8:08	4:30	0:25	87.6	0.1
1:37	1:07	0:18	77.2	7.1	Grn	Green Core	1:41	1:11	0:20	75.4	6.5
4:37	2:38	0:06	89.0	1.6	Grn	Mattapan	4:21	2:38	0:25	80.2	

FULL DAY

Inbound Sched Hdwy	Obsrvd Wait	Excess Wait	% Psgr Waiting < 1 Hdwy	> 2 Hdwy	Line	Branch	Outbound Sched Hdwy	Obsrvd Wait	Excess Wait	% Psgr Waiting < 1 Hdwy	> 2 Hdwy
10:40	6:13	0:40	89.9	2.1	Red	Braintree	10:34	5:58	0:31	87.5	0.7
10:41	5:42	0:09	94.0	0.1	Red	Ashmont	10:37	5:52	0:23	88.0	0.5
5:18	2:57	0:12	88.6	0.4	Red	Alewife	5:21	3:29	0:40	79.3	1.8
7:28	4:58	0:37	85.5	1.4	Org	Oak Grove	7:26	4:56	0:39	86.0	2.2
7:26	4:53	0:36	86.8	1.9	Org	Forest Hls	7:28	5:14	0:53	81.9	2
5:54	4:10	0:26	88.8	0.1	Blu	All Service	5:57	4:19	0:32	86.0	0.3
6:19	4:17	0:46	80.2	3.2	Grn	Boston Col	6:21	4:40	1:04	76.1	3.2
6:31	4:06	0:36	83.4	1.2	Grn	Cleveland	6:31	4:16	0:43	79.9	1.4
6:13	4:31	0:45	79.9	1.9	Grn	Riverside	6:08	5:03	1:16	76.6	6.6
8:52	4:56	0:26	87.7	0.2	Grn	Arborway	8:51	5:00	0:30	87.6	0.4
1:46	1:36	0:34	67.1	11.3	Grn	Green Core	1:44	1:35	0:39	68.1	11
6:57	4:26	0:11	92.9	0.3	Grn	Mattapan	6:57	4:29	0:14	87.7	0.5

FIGURE 5 Sample daily summary report.

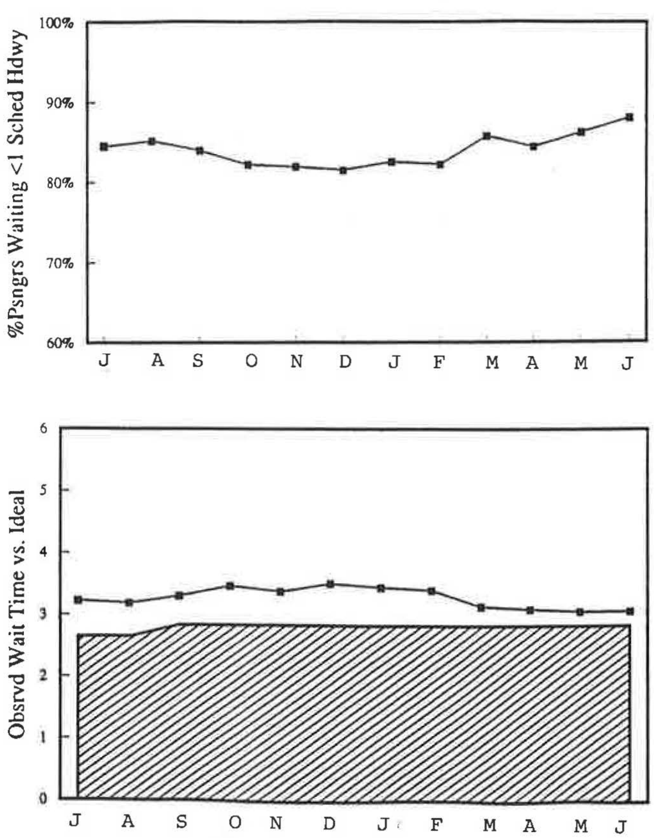


FIGURE 6 Passenger waiting time (*top*) and excess wait time (*bottom*) for Orange Line, p.m. peak period FY91.

times. With an AVI system, each of these problems can be overcome, directly or indirectly.

A final assumption is that the headway distribution observed at a detector is representative of the headway distribution along that segment of the line. This assumption will not always be true; its validity depends on the location of the detectors. In general, the variance of headway increases with distance from the terminus, so detectors located at or near the start of a line tend to underestimate mean passenger wait times on the line as a whole (*9,10*). To minimize this type of bias, if there are only a small number of detectors, they should be located at about the midpoint of the line in terms of cumulative boardings. Alternatively, more detectors can be installed along the line.

Practical Results

The new monitoring system for passenger waiting time was implemented at relatively low cost. Because the system was designed to use the existing hardware for train detection, the initial capital cost of the system consisted primarily of personal computers, color monitors, printers, and communications boards, for a total cost of approximately $35,000. Additional labor costs of $65,000 were incurred to refine the monitoring software and to correct errors in the existing detection equipment. The on-going operating cost of the system is about the same as the Thruput system that it replaced.

The real-time monitoring system and daily reports were tested for 6 months in 1990 before going live July 1, 1990. MBTA managers, while enthusiastic about the passenger orientation of the new system, were initially uncomfortable with the wait-time statistics, because they were not as intuitive as

Thruput data. Once managers began to understand the statistics, action was taken to respond to problems indicated on the real-time system and delays shown in the reporting system were investigated.

The impact of the monitoring system on service quality is difficult to gauge. As noted, the passenger's wait is just one component of a trip. After the first year of monitoring, the percentage of passengers waiting less than one scheduled headway for service has increased by almost two percentage points across the system. There has also been a major reduction in the incidence of delays of more than 5 min. However, no customer surveys have been taken to see if this level of improvement is significant, given the other factors affecting service quality.

Overall, the new system has resulted in a better understanding of the quality of service and in a modest improvement in service, even though it was implemented in a short time at a relatively low cost. To continue to make improvements and to create a more customer-based monitoring system, a higher-cost AVI system would be required.

MORE COMPREHENSIVE SERVICE-QUALITY MONITORING

With AVI systems for vehicle detection, the concept of service-quality monitoring presented earlier can be extended to reflect travel time as well as wait time. A difficulty in this case will be selecting a manageable set of measures from the overwhelming number of options. Using the passenger wait time measures as a guide, the following questions must be addressed:

1. Which origin-destination pairs should be included?
2. Should measures be developed for both ride time and total time?
3. What thresholds should be used for establishing good and bad service?

Any location equipped with an AVI detector is a candidate origin or destination, but even with a small number of detectors on a line, the number of possible origin-destination pairs quickly becomes unmanageable. A reasonable approach is to include the origin-destination pairs that have the highest passenger volumes, with a limit of perhaps four per line in the summary report. It should also be possible to access service-quality data readily on any other origin-destination pair.

Service measures should be calculated separately for wait, ride, and total times. Separate measures for total time are desirable because marginally acceptable wait and ride times may result, if combined, in unacceptably long total times. The computation of ride time measures are independent of the associated wait times, whereas the total time measures are based on the combined headway and ride times for each vehicle.

Finally, there is the issue of thresholds for good and bad service. The ride time equivalent of the scheduled headway is the scheduled vehicle running time between a given origin-destination pair. Commensurate measures of good service would be that the ride time was less than or equal to the scheduled running time, and the total time less than or equal to the sum of the scheduled headway and scheduled running time. A threshold for bad service is more difficult to define. One way to define bad service would be to use one scheduled headway beyond the scheduled running time as the threshold. Another definition would use a percentage of the scheduled running time (e.g., 120 percent of running time). For the sake

Wait Time

Line	O-D Pair	Sched Hdwy	Obsrvd Wait	Excess Wait	% Pass Waiting < 1 Hdwy	% Pass Waiting > 2 Hdwy
	$O\text{-}D_1$					
	$O\text{-}D_2$					
	$O\text{-}D_3$					

Ride Time (RTime)

Line	O-D Pair	Sched RTime	Obsrvd RTime	Excess RTime	% Pass Riding < Sched RTime	% Pass Riding > (Sched RTime + 1 Hdwy)
	$O\text{-}D_1$					
	$O\text{-}D_2$					
	$O\text{-}D_3$					

Total Time (TTime)

Line	O-D Pair	Total TTime	Obsrvd TTime	Excess TTime	% Pass TTime < (Sched RTime + 1 Hdwy)	% Pass TTime > (Sched RTime + 2 Hdwy)
	$O\text{-}D_1$					
	$O\text{-}D_2$					
	$O\text{-}D_3$					

FIGURE 7 Service quality report format.

of simplicity and consistency, using the scheduled headway as a reference is suggested, even though it will tend to set a hard-to-meet standard for long trips on very short headway services.

Figure 7 shows a format for a service-quality report for a single line. A couple of points are worth emphasizing about this figure. First, the scheduled running time is assumed to be the time that passengers expect when they plan a trip. If it is systematically different from the mean ride time, this will show up in the excess ride time measure, and large differences may suggest that the scheduled running time needs adjustment. Second, the ideal total time is the sum of the wait time under scheduled train operations and the scheduled running time, not the sum of the scheduled headway and the scheduled running time.

At this stage the proposed comprehensive service-quality report is just that—a proposal. When AVI systems are installed, it will, no doubt, be modified in light of operational experience, as has the passenger wait time monitoring system at MBTA. Other measures of service quality could be added if APC data were also available, or if passenger flow rates and loads could be estimated with a reasonable amount of reliability from prior system data collection.

This level of detail in service-quality monitoring can be achieved, given the existing data in transit systems such as TTC and BART. However, for an older system to gain the benefits of a more detailed service-quality monitoring system, a major commitment to new automatic detection equipment is necessary.

CONCLUSION

The passenger wait time system implemented for the urban rail lines of MBTA has shown that with crude (in fact, obsolete) train detectors, and without major capital investment, reasonable measures of service quality for passenger waiting time for service can be estimated. The resulting system provides a real-time monitoring capability that is being used in controlling MBTA rail services and providing measures of service quality that can be compared across lines as well as over time. Service measures, which are applicable to any high-frequency transit line, when passengers arrivals can reasonably be assumed independent of the schedule, include expected passenger wait times, differences between actual and ideal service quality, and the percentages of passengers who receive good and bad service. As AVI systems are implemented, at MBTA and elsewhere, the scope of the service-quality monitoring system can be expanded to cover ride and total times as well as wait times.

Thus, transit operators can be more aware of service quality in both planning and operations control by using readily available operations data more effectively. One important result may be a reduction in the difference between operational performance as measured by the transit operator and that experienced by the passenger.

ACKNOWLEDGMENTS

The research described in this paper was performed jointly by MIT and MBTA, with funding provided in part by MBTA.

REFERENCES

1. METRO Houston. *Bus Service Evaluation Methods: A Review.* Report DOT-I-84-49. U.S. Department of Transportation, Nov. 1984.
2. M. Abkowitz, H. Slavin, R. Waksman, L. Englisher, and N. Wilson. *Transit Service Reliability.* Report UMTA-MA-06-0049-78-1. Transportation Systems Center, U.S. Department of Transportation, 1978.
3. J. Koffman and H. Gault. AVLC Data for Planning and Management-Information Overload. *Proc., Automatic Vehicle Location in Urban Transit Systems.* Ottawa, Canada, 1988.
4. C. C. Hodges. *Automatic Passenger Counter Systems: The State of the Practice.* Report DOT-I-87-36. U.S. Department of Transportation, June 1985.
5. L. A. Bowman and M. A. Turnquist. Service Frequency, Schedule Reliability, and Passenger Wait Times at Transit Stops. *Transportation Research*, Vol. 15A, No. 6, pp. 465–471.
6. G. Henderson, P. Kwong, and H. Adkins. Regularity Indexes for Evaluating Transit Performance. In *Transportation Research Record 1297*, TRB, National Research Council, Washington, D.C., 1991.
7. P. I. Welding. The Instability of Close Interval Service. *Operational Research Quarterly*, Vol. 8, No. 3, 1957, pp. 133–148.
8. A. M. Oliver. *The Design and Analysis of Bus Running Times and Regularity.* London Transport, England, 1971.
9. M. D. Abkowitz and I. Engelstein. Factors Affecting Running Time on Transit Routes. *Transportation Research*, Vol. 17A, No. 2, 1983, pp. 107–113.
10. M. D. Abkowitz and I. Engelstein. Temporal and Spatial Dimensions of Running Time in Transit Systems. In *Transportation Research Record 877*, TRB, National Research Council, Washington, D.C., 1982, pp. 64–67.

Publication of this paper sponsored by Committee on Transit Management and Performance.

Random Drug Testing: The Connecticut Transit Experience

David A. Lee

Connecticut Transit (CTTRANSIT) implemented random drug and alcohol testing of its nearly 700 safety-sensitive bus operators and mechanics in September 1990. The CTTRANSIT experience to date is summarized with particular reference to the accuracy and reliability of test results. During the first 17 months of this program, the rate of positive results was 1.91 percent. Significantly, zero false-positive results have occurred among the more than 500 random tests to date at CTTRANSIT. This performance is attributed in large measure to several critical quality-control measures, including confirmation of all initial positive tests using state-of-the-art gas chromatography/mass spectrometry technology, use of a National Institute of Drug Abuse–certified laboratory, and validation of test results by a medical review officer. Other key features of the CTTRANSIT program are detailed. Three important underpinnings of the program at CTTRANSIT include legal authority under a state random testing statute, the company's long-standing drug and alcohol policies, and a nationally recognized employee assistance program. Random testing at CTTRANSIT was specifically upheld in a landmark grievance arbitration award.

In September 1990, Connecticut Transit (CTTRANSIT) became the first public transit system in New England, and one of the largest systems nationwide, to implement random drug and alcohol testing of its safety-sensitive employees. The CTTRANSIT experience during the first 17 months of testing, especially with regard to the accuracy and reliability of random test results is documented.

BACKGROUND

CTTRANSIT is the state-owned operator of public bus transit service in the Hartford, New Haven, and Stamford urbanized areas. CTTRANSIT is the largest all-bus transit system in New England, and employs approximately 535 full-time operators, 175 hourly rate maintenance personnel, and 125 salaried staff in three divisions. The system operates more than 300 peak-hour buses every business day and carries more than 26 million passengers a year.

CTTRANSIT has a strong and long-standing policy regarding drugs and alcohol. At least since 1985, the policy has explicitly prohibited employees from reporting to work, performing work, or being on company property with any detectable level of alcohol or controlled substances in their blood or urine. The only exception is medications that the prescribing physician certifies will not affect the employee's safety performance.

Connecticut Transit, 100 Leibert Road, Hartford, Conn. 06141.

In 1987 the Connecticut Legislature passed An Act Concerning Drug Testing in the Work Place, which defined employers' authority in three important areas. This legislation at the time was considered to be pro-labor because it restricted employers' rights to impose random testing for all employees (*1*, p. B5).

1. The statute establishes an employer's right to conduct preemployment and reasonable suspicion testing of all employees. However, the latter is specifically limited to reasonable suspicion of current impairment. Thus, some indicators used by employers in other states to warrant for-cause testing—such as deteriorating job performance, the occurrence of an accident, or possession of drug paraphernalia—would not permit a reasonable suspicion test in Connecticut. Under the state statute, a urinalysis test is permitted only when an employee's observed and documented actions, appearance, or behavior, or all three, support reasonable suspicion of current impairment.
2. Random testing is permitted, but only for employees in safety-sensitive occupations as defined by the state commissioner of labor.
3. The statute requires various quality controls to ensure the accuracy and reliability of test results with a mandatory confirmation of all positive tests. The statute also guarantees employees' privacy while providing urine specimens and the right to have specimens retested at another laboratory.

The 1987 statute had little immediate effect on existing CTTRANSIT policy or procedures. In summer 1988, the State Department of Labor initiated a rule-making process for the designation of safety-sensitive occupations. The designation procedures were still being developed in November 1988, when the former UMTA (now Federal Transit Administration or FTA) issued final rules mandating random (as well as certain other) urinalysis testing of safety-sensitive transit workers nationwide.

The deadline for certifying compliance with the UMTA regulations was December 22, 1989. Less than 4 weeks later, however, a federal appeals court struck down the UMTA mandate, citing the agency's lack of regulatory authority [Amalgamated Transit Union et al. v. Skinner, No. 89-5380 (U.S. App. D.C., Jan. 19, 1990)]. Meanwhile, the process for designating safety-sensitive occupations in Connecticut continued, and on February 6, 1990, the state labor commissioner determined that bus operators and mechanics could be subject to random testing under the state statute.

It is interesting to note that the labor department did not accept the UMTA definition of safety-sensitive occupations, which would have included transportation supervisors, dispatchers, and maintenance foremen. In Connecticut, only occupations that operate a revenue service vehicle, whether or not such vehicle is in revenue service, and that maintain revenue service vehicles or equipment used in revenue service were designated. At CTTRANSIT, this definition includes all bus operators (CTTRANSIT does not employ part-time operators) and all hourly rate maintenance department employees except building maintainers, building cleaners, and parts clerks.

At CTTRANSIT, negotiations for a new union contract began March 1, 1990, and plans to implement random testing were discussed between the parties during several of the bargaining sessions (CTTRANSIT bus operators and hourly rate maintenance employees are represented by three local divisions of the Amalgamated Transit Union). Although agreement on an overall program to include random drug and alcohol testing was not reached, several changes to the company's initial proposal were made in response to union comments:

1. A breathscan technique (confirmed, if positive, with a blood test) was substituted for urinalysis to detect blood alcohol content (BAC).
2. Under the original proposal, employees testing positive would be ineligible to use sick leave while disqualified and their company-paid insurance benefits would cease. For an initial 6-month period, this was changed to provide continuation of medical insurance and to permit sick leave if the employee's clinical assessment recommended treatment for an illness.
3. Although CTTRANSIT's long-standing policy provides zero tolerance for controlled substances, the company agreed to specify the drugs covered by urinalysis testing and to use the industry-standard cutoff levels for determining a positive result.
4. Consistent with the U.S. Department of Transportation (DOT) protocols, the company originally proposed that employees reinstated after a positive random test would be subject to periodic, unannounced testing for 60 months. The union objected, stating that 60 months was unreasonable, and the company agreed to reduce the period for unannounced testing to 36 months.
5. Other changes in the proposal included overtime pay for employees tested outside their normal working hours and an agreement was made to pay the cost of the periodic, unannounced tests performed after the employee returns to work.

Despite these changes, agreement on a random drug and alcohol testing program was not reached. Notwithstanding the union's basic objection in principle to random testing under any circumstances, the major impasse was whether employees must be afforded a right of access to rehabilitation and reinstatement (i.e., a guaranteed second chance). The company informed the union of its intention to impose random testing unilaterally under the authority of state statute and the management rights provision of the union contract.

On July 12, 1990, the company's long-standing Rules Regarding Alcohol and Controlled Substances were reissued, including a new provision for random testing of all safety-sensitive employees. Significantly, the commencement of random testing was delayed approximately 6 weeks until September 1 in order to provide an additional opportunity for employees whose alcohol or drug use may have resulted in a positive test to seek help voluntarily through the company's employee assistance program (EAP).

A union grievance was filed immediately after the program was announced, challenging management's basic right to impose random testing. The grievance was still pending when random testing commenced on September 1, 1990, and testing proceeded for more than a year before the final arbitrator's award was received in November 1991. In a decision that may have a significant implications for other employees, arbitrator George Schatzki, a former dean of the University of Connecticut School of Law, denied the union's grievance in all particulars, except for two procedural issues involving vacation pay and sick leave for disqualified employees and payment of the cost of "return to work" tests (*2*). Specific issues addressed in the arbitrator's award include the following:

1. *Is random drug testing an unconstitutional waiver of employees' privacy rights*? No. There is ample legal precedent to establish that employees in safety-sensitive occupations have a diminished expectation of privacy.
2. *Did CTTRANSIT violate the National Labor Relations Act (NLRA) by imposing random testing unilaterally*? No. The company did negotiate elements of the program and repeatedly expressed a desire to reach agreement. In effect, the parties reached a stalemate on key issues of principle and, therefore, agreed to disagree. The union had other remedies available under the NLRA that it did not pursue.
3. *Is random testing an unreasonable rule under the terms of the management rights clause of the union contract*? No. Public safety is a paramount concern for transit management that warrants special measures to detect and deter violations of drug and alcohol rules. It is not necessary to prove widespread, ongoing drug and alcohol abuse by safety-sensitive employees to warrant random testing.
4. *Must employees who fail a random test be guaranteed a right to rehabilitation and reinstatement*? No. It is not inherently unreasonable for management to retain discretion to deny employees a second chance on the basis of individual circumstances. However, the exercise of management discretion in individual cases is subject to appeal through the grievance process.

About the Random Testing Program

CTTRANSIT and 20 other publicly funded operators participate in a statewide drug testing consortium that was originally formed by the smaller operators in Connecticut to comply with the UMTA rule. The consortium, in turn, has contracted with a private firm to administer the testing program. Specific services of the contractor include maintaining the computerized employee data base and performing the random selections each month; arranging for local collection sites and chain of custody procedures; providing a National Institute on Drug Abuse (NIDA)-certified laboratory; and providing a qualified medical review officer (MRO). CTTRANSIT initiated random testing ahead of the other consortium members. However, since May 1991, all safety-sensitive employees of consortium members have been subject to random testing. Individual employer policies and procedures for employees who test positive may differ substantially from those used at CTTRANSIT.

Random testing is performed at the 50 percent level (i.e., a number of tests equal to one-twelfth of 50 percent of all safety-sensitive employees in the data base is scheduled each month). The program at CTTRANSIT conforms to all of the DOT drug testing protocols that would have governed testing under the UMTA rules (*3*), including use of a NIDA-certified laboratory and medical review officer. In three areas, the CTTRANSIT program actually goes beyond the minimum federal requirements as follows:

1. CTTRANSIT tests for 10 controlled substances plus alcohol, not just the "federal five" illegal drugs. These substances include cannabinoids, cocaine, amphetamines, opiates, phencyclidine, barbiturates, benzodiazepines, methadone, methaqualone, and propoxyphene. Industry-standard cutoff levels are used to detect drugs in urinalysis. A breathscan technique for alcohol is administered at the same time urine is collected for drug testing. If the breathscan is positive, a blood sample is collected for confirmatory testing and to quantify the BAC.
2. CTTRANSIT further randomizes the monthly list of employees selected for testing by week of the month, day of the employee's workweek, and hour of the workday. For random testing to provide an effective deterrent to prohibited use of alcohol or drugs, CTTRANSIT believes employees must recognize that they are subject to a random test any time they are on duty.
3. State statute requires two confirmations of a positive initial urinalysis screen. As with the DOT protocols, the final confirmation must use the gas chromatography/mass spectrometry (GC/MS) methodology.

Accuracy in Transit Drug Testing

Presentations by Barnum and Gleason at the 1990 and 1991 Transportation Research Board annual meetings have raised serious questions about the potential for inaccuracy in transit drug testing (*4,5*). Most disturbing is their conclusion that testing is likely to produce a significant number of false-positive results. In fact, as evidence that random testing is unreasonable and unwarranted, the following quotation from their 1990 paper was cited in the union's grievance at CTTRANSIT (the union did not pursue this issue further during the arbitration. However, the neutral arbitrator did take note that testing procedures used by CTTRANSIT conform in all respects to federal and state requirements) (*4*):

> Thus, almost two out of every five workers testing positive will truly be drug free! With probabilities such as these, it is highly unlikely that a positive drug test would provide a preponderance of evidence that an individual was taking drugs, let alone meet higher levels of proof . . . Not only would employers lose arbitration or court cases with such meager evidence, it would seem illogical, from the standpoint of good personnel practice, to dismiss or discipline employees with such unreliable evidence (*5*).

In their published closure to a DOT rebuttal of their 1990 paper, Barnum and Gleason demurred: "We were very careful not to claim that drug testing will result in high percentages of those testing positive being falsely identified." Instead, the authors emphasize that their estimated rates of false-positive test results "are ones that could occur in some circumstances" (*4*).

The Barnum and Gleason papers have developed important hypothetical data about transit drug testing by applying analytical techniques to baseline data originally published in 1985 and 1988 in the *Journal of the American Medical Association* (JAMA) (*6,7*). Significantly, however, their conclusions appear not to have been tested against the actual experience of transit systems. The experience of CTTRANSIT documented in the following should help to illuminate the overall issue of accuracy in transit drug testing.

It is also important to note that the baseline data published in JAMA did not specifically address several key quality-control measures that are integral to the DOT and CTTRANSIT drug testing procedures. Thus, the CTTRANSIT experience underscores the importance of maintaining high-quality standards to maximize the accuracy and reliability of results. In particular, four measures have been found to be most important:

1. Confirmation of all positive test results—At least some initially positive drug screens reported in JAMA were not confirmed. After reviewing the results of their study, the 1988 JAMA authors concluded, "It is clear that mandatory confirmation of initial screening tests must be required" (*7*). As indicated earlier, DOT protocols specifically require confirmation of all positive tests; in fact, the Connecticut statute requires two confirmations.
2. Confirmation with GC/MS methodology—The state-of-the-art methodology for urinalysis drug testing is GC/MS. GC/MS has been proven to be far more accurate than simpler and less expensive techniques such as thin-layer chromatography and immunoassays (*8*). Again, both DOT protocols and Connecticut statute specifically require confirmation of positive results using GC/MS. By contrast, some of the laboratories cited in the JAMA articles did not have GC/MS capability. Many positive test results were apparently confirmed with less accurate and less reliable techniques.
3. NIDA-certified laboratory—Drug testing results documented in the JAMA articles were gathered from a wide range of laboratories that "was not intended to be a representative sampling, nor was any attempt made to choose laboratories of any particular size or presumed reliability." A particular concern expressed by the 1988 JAMA authors was a lack of certification standards for drug-testing laboratories. Responding to what they called sorely needed standards and means for improving laboratory quality, the authors cited an ongoing effort by NIDA to develop standards of laboratory accreditation (*7*). This effort resulted in extremely rigorous national certification standards that fewer than 75 laboratory sites nationwide had met by mid-1991. It is again significant that both DOT protocol and CTTRANSIT policy require drug testing to be performed only by a NIDA-certified lab.
4. Medical review officer (MRO)—Laboratory test results are not reported to the employer until they have been reviewed by a specially qualified physician who acts as the MRO. In turn, the MRO will not report a positive test until he or she has personally discussed the result with the employee in question and determined that the laboratory result is valid.

The MRO follows a detailed *Medical Review Officer Manual* produced by NIDA that guides the evaluation of laboratory urinalysis results (*9*). During the first 17 months of testing at CTTRANSIT, three employees' tests that were confirmed positive by the laboratory were reported negative after MRO review. One involved a prescription drug and two involved poppy seeds. Our experience strongly supports the integral role of an MRO in the urinalysis testing process, especially if testing is performed for substances that may be contained in prescription medications.

Results of Testing at CTTRANSIT

From September 1990 through January 1992, 509 random drug and alcohol tests were performed at CTTRANSIT. This number includes 375 tests of bus operators, 96 tests of hourly rate maintenance department employees, and 38 tests of salaried managerial and supervisory employees who voluntarily participated in a separate random-selection pool. None of the salaried employee tests was reported positive.

Of the 471 random tests of safety-sensitive employees to date, 9 or 1.91 percent, were reported positive. Of the nine positive results, four were for marijuana and five were for cocaine. Six of the individuals testing positive were bus operators (1.60 percent of all random tests of operators), and three were maintenance employees (3.13 percent).

An employee whose random test result is positive is disqualified from employment at CTTRANSIT and may then apply for reinstatement. The first step in this process is examination by a professional assessment clinician engaged by the company. The clinician's assessment report specifies the nature of the employee's alcohol and drug use, recommends specific rehabilitation or treatment that the employee should be required to complete before reinstatement, and comments on the probability of successful rehabilitation.

Significantly, in all nine positive random test cases to date at CTTRANSIT, the employees involved admitted using drugs in violation of the company's policy. Given the vigorous union representation of employees disqualified at CTTRANSIT because of drug testing, it is inconceivable that a truly drug-free individual confronted with a positive test result would not immediately and vociferously protest. State statute also guarantees employees the right to have their urine specimen retested at another laboratory.

The potential problem of false-positive drug test results is self-policing to the extent that no false-positive result would go unchallenged. We can state unequivocally that at CTTRANSIT, out of more than 500 random tests performed to date, no false-positive results have occurred.

Arguably, the three cases for which positive laboratory results were reported negative by the MRO should be considered false positives. However, the MRO is as integral a part of the testing process as the laboratory itself. The chief concern about random testing expressed by Barnum and Gleason (*4,5*), among others, is that a truly drug-free individual might be falsely charged with violating company policy and subjected to discipline, even termination. As such, we believe our experience demonstrates the effectiveness of a drug-testing process that includes MRO review. The employer is not informed of which employees' test results were involved. Again, the only tests at CTTRANSIT that were confirmed positive by the laboratory and reported as such by the MRO were, by the employees' own admissions, proven to be true-positive results.

The nature of drug abuse by individuals testing positive has been varied. However, in none of the nine cases was the employee assessed as having a drug addiction, and in none was hospitalization or other in-patient treatment for an illness recommended. In five cases, the individuals could be categorized as recreational drug users who, in the words of one's clinical assessment, "made a naive and thoughtless mistake with [cocaine]." In other cases, drug use appeared to be symptomatic of a complex of other personal and family problems. In all nine cases, counseling provided on an outpatient basis was recommended, and, in most cases, this counseling was to continue for some period as a condition of reinstatement.

Before reinstatement, a disqualified employee must enroll in the recommended rehabilitation program, provide evidence of satisfactory participation, pass a physical examination by a company-appointed doctor, and pass a new urinalysis and breathscan test. All nine employees who failed random drug tests subsequently met the conditions for reinstatement and returned to work.

A key condition of employees' reinstatement after a positive random drug test is periodic, unannounced testing at the company's discretion. As indicated earlier, although DOT provides periodic, unannounced testing for 60 months, CTTRANSIT agreed during negotiations with the union to reduce this period to 36 months.

Periodic, unannounced testing is more intensive during the first 6 months after reinstatement. For example, 10 unannounced tests during the first 6 months would be considered reasonable under the CTTRANSIT program. Thereafter, the frequency of unannounced testing would normally decrease. Tests are scheduled deliberately for maximum effectiveness in monitoring and deterring violations of company rules. Thus, special emphasis is given to scheduling some tests on the day after payday, the morning after an employee's regular days off, the day an employee returns to work from vacation or sick leave, and, on at least one occasion, on consecutive days.

Once an employee has been reinstated after a positive test for drugs or alcohol, he or she is subject to discharge without recourse to rehabilitation if any subsequent random, reasonable suspicion, or periodic unannounced test result is positive. At this writing, three of the nine reinstated individuals have failed unannounced tests (two for cocaine, one for marijuana) and have been discharged.

Keys to Successful Implementation

Even with the underpinning of state statute and public policy, random testing remains a controversial workplace issue. In large part, the successful implementation of random testing at CTTRANSIT was made possible by three important factors that should be considered by other operators contemplating similar programs.

Alcohol and Drug Policy

CTTRANSIT had a strong and long-standing policy prohibiting drugs and alcohol in place for many years before random testing began. As indicated earlier, the basic rule prohibits employees from reporting for work, working, or simply being on company property with any level of alcohol or drugs detectable in their urine or blood. Thus, at CTTRANSIT, random testing did not constitute a change in the company's basic rule or set a new standard of employee conduct. Instead, random testing represented a new way to monitor compliance with an existing rule. Also, because the long-standing rule defining prohibited conduct had not been challenged, it was easier to represent random testing as a necessary measure to deter—as well as detect—violations of the basic company policy.

Employee Assistance Program

The EAP at CTTRANSIT has evolved over 15 years from what was originally a self-help and peer referral program that emphasized alcoholism recovery to a broad-brush, full-service program that is recognized as a model for other operators nationwide (*10,11*).

Employers and union groups sometimes mistakenly associated EAPs only with drug and alcohol treatment. CTTRANSIT was concerned that directly linking the EAP with drug testing would undermine two critical features of the program: strict confidentiality of voluntary contacts and broad-brush services to help individuals deal with virtually any type of personal or family problem. Thus, for example, the company deliberately engaged assessment clinicians from outside the EAP network.

However, having an effective and widely accepted EAP in place clearly helped to make random drug and alcohol testing more credible by ensuring help for employees before testing commenced. In effect, individuals who now test positive do so despite the company's best efforts to offer strictly confidential EAP services at no cost to employees who access the program voluntarily. The EAP also plays an important role in education and training programs to heighten all employees' awareness about drug and alcohol abuse, and it can provide aftercare monitoring and support for employees after reinstatement.

Testing Procedures

In the absence of national standards for random drug testing by transit operators, there is justifiable concern that some local programs may compromise accuracy and reliability by cutting corners. Barnum and Gleason have warned, "Given the large number of small transit organizations operating under very diverse conditions, and with many agencies neither skilled nor truly concerned about drug testing, the potential for error is high" (*5*). In that regard, smaller operators in other states may find a helpful model in the Connecticut consortium approach.

Other Features of CTTRANSIT Program

Maintaining the highest standards to ensure accuracy and quality in transit drug testing has proved critical in the CTTRANSIT experience—particularly to make the program credible to employees and their union representatives. In addition to the four quality measures discussed earlier, three other features of the CTTRANSIT program bear mentioning.

Collection Sites

As a general policy, urine is collected and breathscan tests are administered off-site at a doctor's office, immediate medical care facility, or, if necessary, a hospital. We believe this improves quality control in the collection process and chain-of-custody, provides greater confidentiality for employees being tested, and places drug testing in the environment of a professional medical facility. Also, because a positive breathscan must be confirmed with a blood test, using medical facilities for collection sites ensures that qualified personnel will be available to draw a blood sample if needed. Finally, employees using drugs or alcohol may attempt to feign sudden illness to avoid being tested. Because such employees are already being transported to a medical facility for their urine collection and breathscan, claiming sudden illness cannot excuse the employee from being tested. Rather, the employee is ensured that he or she can receive medical attention at the collection site. These issues should also be considered carefully by transit systems implementing postaccident testing.

Scheduling of Tests

To maximize the deterrent value of random testing, the program at CTTRANSIT is administered so that any safety-sensitive employee is potentially subject to a random test at any time he or she is reporting for work or on duty. This policy requires special arrangements in order to perform collections 24 hr a day, 365 days a year.

Transporting Employees to Collection Site

Employees selected for random testing are transported to and from the collection site by a supervisor. The supervisor remains with the employee from the time the employee is told he or she is being taken for a random test until the employee is turned over to collection site personnel. This practice is intended to prevent an employee from tampering or faking illness or injury en route.

These measures, along with the company's decision to test for 10 controlled substances plus alcohol, add a cost and administrative burden. In our view, the effectiveness of random testing, especially as a deterrent, generally depends partly on the commitment of management to ensure the most comprehensive, professional, accurate, and reliable program possible.

CONCLUSIONS

Random drug and alcohol testing of safety-sensitive employees has been implemented successfully at CTTRANSIT. A number of important quality-control measures that are integral to the overall program are emphasized. We credit these measures in large degree with maintaining a 0 percent rate of false-positive results over more than 500 random tests performed to date.

The overall rate of positive test results, 1.91 percent to date, was not unexpected (*4*). However, with random testing only at the 50 percent level, it is not believed that definitive conclusions about the overall rate of drug use among employees can be drawn with less than 2 full years of experience.

Given a public transit operator's overriding responsibility to maintain the highest standards of public and employee safety, we believe random drug and alcohol testing is warranted. It is arguable, however, once it became possible under state statute, the management of any safety-sensitive enterprise in Connecticut could not responsibly decline to implement random testing.

Clearly, the purpose of the program is to deter violations of a long-standing drug-free workplace policy and to detect violators. At this time, we have only anecdotal evidence to suggest that random testing has indeed achieved a deterrent effect within the workforce. This issue may provide a fruitful topic for further study elsewhere.

Finally, Congress has recently passed new legislation authorizing FTA to re-issue drug testing regulations, including a provision for alcohol testing. The federal mandate explicitly supersedes contrary provisions of state or local statute. It is unknown how such regulations will affect the CTTRANSIT program. However, some likely changes will include postaccident testing, a broader definition of safety-sensitive employees, alternative breath-testing methodologies for alcohol, and possible requirements for a separate urine collection in order to test drugs other than the "federal five." Otherwise, we believe that the existing program at CTTRANSIT provides, in many respects, a model for transit systems that are required to implement random testing.

REFERENCES

1. M. Remez. Labor, Business Groups to Square Off Over Workplace Drug Testing. *Hartford Courant*, Dec. 24, 1990.
2. G. Schatzki. *Opinion and Award in the Arbitration Matter of Locals 281, 425, and 443*. AAA No. 12-300-00562-90. Amalgamated Transit Union and HNS Management Company, Inc. Nov. 1991.
3. U.S. Department of Transportation, Office of the Secretary. *Procedures for Transportation Workplace Drug Testing Programs*. 49 C.F.R. Part 40, Nov. 21, 1988.
4. D. T. Barnum and J. M. Gleason. Accuracy in Transit Drug Testing: A Probabilistic Analysis. In *Transportation Research Record 1266*, TRB, National Research Council, Washington, D.C., 1990, pp. 10–18.
5. D. T. Barnum and J. M. Gleason. Determining Drug Test Accuracy: The Multidrug Case. In *Transportation Research Record 1297*, TRB, National Research Council, Washington, D.C., 1991, pp. 20–31.
6. H. J. Hansen et al. Crisis in Drug Testing. *Journal of the American Medical Association*. April 26, 1985, pp. 2382–2387.
7. K. H. Davis et al. Assessment of Laboratory Quality in Urine Drug Testing. *Journal of the American Medical Association*. Sept. 23/30, 1988, pp. 1749–1754.
8. L. I. Dogoloff and R. T. Angarola. *Urine Testing in the Workplace*. American Council for Drug Education, Rockville, Md., 1985.
9. *Medical Review Officer Manual: A Guide to Evaluating Urine Drug Analysis*. National Institute on Drug Abuse. U.S. Department of Health and Human Services, Sept. 1988.
10. D. A. Lee. Employee Assistance Programs in the Public Transit Industry: Experience of Connecticut Transit and Some Concerns for the Future. In *Transportation Research Record 1266*, TRB, National Research Council, Washington, D.C., 1990, pp. 3–9.
11. ETP, Inc. *Employee Assistance Programs for Transit Systems, a Procedural Guide and Model*. Final Report. Office of Technical Assistance and Safety, UMTA, Sept. 1991.

Publication of this paper sponsored by Committee on Transit Management and Performance.

New Future for Federal Transit Administration Section 15 Program

WILLIAM M. LYONS AND EDWARD R. FLEISCHMAN

The results of an extensive evaluation conducted by the Federal Transit Administration (FTA) into the future of the Section 15 Uniform System of Accounts and Records and Reporting System are reported. On the basis of this evaluation, FTA will implement major structural and procedural changes to reduce the burden of reporting and improve the value of the data for analysis. The structural changes to the Section 15 program that are to be made through the rulemaking process are discussed. FTA published an Advanced Notice of Proposed Rulemaking that identified alternative changes and related issues and a Notice of Proposed Rulemaking (NPRM) that described FTA's proposed changes. From public comments, FTA will publish a rule to implement major changes. Because rulemaking is under way, the progress through the NPRM stage is the focus of the discussion. FTA applied a benefit-cost approach to consider trade-offs between the usefulness of the data base and the burden of reporting. FTA considered fundamental objectives of the program and its strengths and weaknesses from the perspective of 14 years of data base production. The major structural changes proposed to reduce the burden of reporting include replacing the current three voluntary and one required report levels with a simplified structure; reducing voluntary financial details by over half; replacing the balance sheet with sources and uses of capital; and raising the threshold for complete reports on contract service from 50 to 100 or more vehicles. To ease reporting and data access, FTA will improve program operations through computerized reporting, new reports on national trends and operators' performance, and more accessible computerized data.

The Federal Transit Administration (FTA) is nearing completion of a comprehensive formal evaluation into the future of the Section 15 Uniform System of Accounts and Records and Reporting System (the Section 15 program) that has been in operation for 14 years. On the basis of this evaluation, FTA will implement major structural and procedural changes to reduce the burden of reporting while improving the value of the data for a range of important local and national applications.

The Uniformed System of Accounts and Records and Reporting System were authorized in 1974 under Section 15 of the Urban Mass Transportation Act of 1964, as amended, and prescribed in January 1977, as called for in the law. Section 15 requires the Secretary of Transportation to establish a uniform system of accounts and records and a reporting system to collect and disseminate public mass transportation financial and operating data. More than 500 public transit operators use the Section 15 systems to record summary information in annual reports to FTA.

W. M. Lyons, John A. Volpe National Transportation Systems Center, U.S. Department of Transportation, Kendall Square, Cambridge, Mass. 02142. E. R. Fleischman, Federal Transit Administration, U.S. Department of Transportation, 400 Seventh Street, S.W., Washington, D.C. 20590.

The Section 15 program provides the sole source of standardized and comprehensive data for use by all constituencies of the transit industry. Section 15 information is used for management and planning by transit systems and for policy analysis and investment decision-making at all levels of government. It provides a resource for consultants, researchers, and industry suppliers. In addition, the Section 9 formula apportions more than $1.5 billion in FTA grant funds annually based on a statutory formula that in part uses Section 15 data. No grant may be made under Section 9 unless the applicant and beneficiaries of the grant are subject to both the Reporting System and the Uniform System of Accounts and Records prescribed by Section 15.

At a national level, Section 15 data are the foundation for the annual summaries of the U.S. public transit industry by the U.S. Department of Transportation in its multimodal report, the White House Council on Environmental Quality, the United Nations, and the American Public Transit Association (APTA). The Section 15 structure and definitions have provided a valuable model for international data bases and analyses (*1*). For example, the Section 15 systems provided the structural model used by the European Conference of Ministers of Transport in multinational research projects on international public transport subsidies (*2*) and the economics of light-rail systems (*3*).

Throughout its review, FTA solicited and received a broad range of comments and recommendations from experts representing operators, public agencies, academia, consultants, and other constituencies of the public transit industry. Detailed recommendations and proposals were received from the FTA Section 15 Reporting System Advisory Committee (*4*), the APTA Section 15 Committee (*5*), TRB, and other representatives of the public and private sectors.

As part of the review, FTA initiated a rulemaking process to discuss, propose, and ultimately implement changes to the program. On August 13, 1990, FTA published an Advanced Notice of Proposed Rulemaking (ANPRM) that identified issues and invited comments on a broad range of changes proposed by industry constituencies (*6*). FTA then published a Notice of Proposed Rulemaking (NPRM) that summarized the 59 public comments on the ANPRM and identified and explained the changes FTA proposed to make to the program (*7*).

FTA is now developing a final rule that will discuss ANPRM and NPRM comments and implement major changes to the program. When completed, the rulemaking will result in major improvements to the Uniform System of Accounts and

Records and Reporting System and will represent a major stage in the 14-year evolution of the Section 15 program. If FTA is able to publish the final rule early in 1992, many of the structural changes described in the rule could be effective for the 1992 report year.

This report focuses on the broad range of structural changes proposed through the rulemaking process. In evaluating the proposed changes, FTA applied a benefit-cost approach to consider trade-offs between the usefulness of the data base and the burden of reporting. The objective was to present a clear picture of who would gain or lose under each proposal and the extent of these gains or losses. FTA considered the potential effects of proposed change from three separate perspectives.

From a reporter's perspective, changes in reporting requirements and procedures can

- Require a one-time cost for revising a reporter's chart of accounts and associated accounting software,
- Increase or decrease the annual cost of data collection, and
- Increase or decrease the annual cost of data reporting.

From FTA's perspective, changes in reporting requirements and procedures can

- Require a one-time cost for revising reporting forms and instruction manuals, retraining the data validation contractor, revising data base formats, redesigning data validation checks, redesigning the annual report, revising data validation and report preparation software, producing documentation to advise data users of structural changes, particularly those that affect time-series analyses, and providing training to reporters and data users; and
- Increase or decrease the annual cost of data validation and annual report preparation.

From a user's perspective (users include operators, consultants, FTA, other federal agencies and state and local governments), changes in reporting requirements and procedures can

- Increase or decrease the number of data items available (i.e., reflecting changes in the types of information and levels of detail provided);
- Increase or decrease the number of observations for a particular data item (i.e., the number of agencies reporting that data item);
- Increase or decrease the accuracy with which a particular data item is reported;
- Increase or decrease the consistency of data among reporters in terms of how definitions are interpreted; and
- Increase or decrease the comparability of data with those of prior years (i.e., for time series analyses).

The fundamental issue is what data items provide valuable enough information to justify the burden of reporting and not the number of pages or forms required. When possible, FTA estimated the numbers of reporters who would have increased or decreased requirements.

In general, the proposals ease the burden of reporting by simplifying or eliminating requirements and clarifying ambiguities. The proposals also increase the value to analysts of the data base for the following reasons:

- Simplified details and procedures will result in improved data quality;
- All data will be easily accessible through reports and computer media; and
- Capital cost data, which have long been a weakness in the systems, will be improved by replacing the balance sheet with annual sources and uses of capital.

To ease reporting and data access, FTA will undertake a broad range of operational improvements to the program, including streamlined forms and instructions, automated reporting, new reports, and more accessible computerized data.

PROPOSED MAJOR CHANGES

The proposed major changes are as follows:

- The basic reporting structure will be simplified. The current structure of the three voluntary and one required report levels will be replaced with a simplified structure and fewer details.
- Voluntary-level financial details, the most complex component of the systems, will be reduced by over half.
- The threshold for complete reports on purchased transportation service will be increased from the current 50 or more vehicles to 100 or more vehicles. This change will decrease the reporting burden by allowing more contract services to be reported using a basic subset of forms.
- Security and ticketing costs will be moved from the administration to the operations grouping. This change responds to industry concern that the systems exaggerate administrative costs. The cost of this more logical alignment could be a reduction in the historical continuity of summary expenses for most reporters.
- Capital reporting will be revised by adding sources and uses of capital in place of the balance sheet. This proposal overcomes a major weakness in the application of Section 15 data. The absence of capital costs has encouraged an overemphasis on operating, rather than capital, costs, which can distort comparisons between modes or operators with varying degrees of labor or capital.
- Accounts will be redefined and employee contributions will be eliminated on the fringe benefits schedule. This revision simplifies reporting with only a minor loss in data.
- Labor equivalents will be redefined. Measuring labor in terms of hours rather than in the form of an arbitrary national standard for a labor year will increase data consistency without increasing burden.
- Fleet inventory information from three different forms will be consolidated onto a single form.
- Reports of operators' work time will be restructured. This proposal greatly simplifies reporting with only a minor loss in data.
- The option of indicating the percentage of paid hours by part-time operators will be added. These data will be valuable in assessing the effect of part-time labor on performance.

• The following required reports will be eliminated because their reporting burden outweighs the value of the data to analysts.

—Pension plans: these data are inapplicable to many operators, difficult to compile, and seldom used in analysis.

—Balance sheet: these object classes are inconsistently reported and of minimal value to analysts.

MAJOR ISSUES

FTA considered the fundamental purpose of the Section 15 systems and whether the systems should continue or be significantly modified in the future.

As stated in the Urban Mass Transportation Act, the Section 15 systems were designed to provide information on which to base planning for public transportation services and public sector investment decisions at all levels of government. FTA asked how successfully Section 15 provides information required by the transit industry, including federal, state, and regional policy-makers, local transit operators, consultants, suppliers, and academic researchers, while limiting the costs and burden of reporting. Does the current structure, format, and content represent a successful compromise among competing interests, or are changes necessary?

Industry respondents found Section 15 to have a broad range of applications, e.g., as a source of standardized definitions, as a resource for academic research, and for local management use. Some respondents expressed the opinion that Section 15 is most useful for national policy analysis. Although some respondents found it unsuitable for local management and planning, particularly for small systems, others found Section 15 useful for local applications. In general, the program was found to satisfy legislative intent, although many respondents advocated improvements in reporting or streamlining of content to improve the balance between the burden of reporting and the value of data.

Comments from the transit industry and the public universally supported continuing the Section 15 program. Numerous comments requested a reduction in the level of required details, particularly for smaller operators. These and other proposed operational improvements to the program are discussed later in this study.

STRUCTURAL ISSUES

This section focuses on proposed changes to fundamental aspects of the structure of the Section 15 Systems. These proposals and related issues discuss several components of the systems or address areas identified by respondents as major weaknesses. Proposals to modify specific components of the systems are described later.

Number and Type of Reporting Levels

A major characteristic of the current structure is the use of various reporting formats. The required (R) level applies to all operators and specifies the minimum data that must be reported by all beneficiaries of FTA Section 9 funds. Operators currently have the option of reporting additional details at any of three voluntary levels (A, B, or C). In order of detail, the A-level requires the most information, followed by levels B, C and R.

The only difference between the required and voluntary levels of reporting is the amount of detail provided for operating expenses and revenues. All other information is required of all reporters and is filed on the same forms. Voluntary levels of expense and revenues have the same basic structure as the required level, but they expand into greater detail. There is no difference in the underlying Uniform System of Accounts and Records.

Although FTA suggests that operators with certain fleet sizes report at specific voluntary levels, this is not a requirement. Several of the largest operators report at the required level, whereas some small operators report at voluntary levels. Operators that received FTA grants for management information systems (MIS) have been obligated to report at voluntary levels. Beginning with the 1991 report year, reporters who received MIS grants will have been able to report at either the voluntary or required level.

Considering the usefulness of a data base that provides various levels of financial details for operators, FTA asked whether voluntary reporting should continue. Is a subset of the national data base that contains more detailed information valuable to analysis or does it encourage biased results? Is the current system unnecessarily burdensome or excessively detailed? And how many levels should there be, whether required or voluntary?

The evaluation showed a great range of views on voluntary reporting and the number of reporting levels. In response to the ANPRM, six respondents supported voluntary reporting, with three in favor of the current approach. Of the 22 comments advocating required reporting only, 10 supported one level, 10 supported two levels, and 1 each supported three and four levels. In addition, two comments supported establishing a new, less-detailed level for small operators.

In its evaluation of proposals to change the current approach to reporting expenses and revenues, FTA concluded the following in the NPRM:

1. The current structure is unnecessarily complex; the value to analysts of many voluntary expense and revenue details is insufficient to justify their continued reporting.
2. The current required level alone does not provide enough details on costs and revenues to meet Section 15 program objectives of providing data to support management, policy, and investment analysis.
3. FTA will strive to limit net increases in financial reporting requirements for the large number of operators reporting at the minimum level who have increased requirements under any proposals for two or more required levels.
4. Most large operators have internal accounting systems, based on the Section 15 Accounting System, that have a greater level of detail than is currently required.
5. Forms or data cells that are inapplicable to most operators do not create a reporting burden for those operators. For example, the existence of expense details on maintenance of roadway and track or communications systems do not cre-

ate a burden to the majority of operators who can ignore these cost items.

6. Data reported for some, but not all, operators have valid and important applications. Valuable and undistorted analysis can be performed by using an incomplete data set if sources are identified and no universal conclusions are attempted without statistically valid methods. For example, voluntary costs such as fare collection, maintenance of roadway and track and passenger stations, and security could be useful in deriving unit costs for analysis for investments in alternative modes.

On the basis of these conclusions, FTA made the following proposals in the NPRM:

- The current structure of three voluntary levels and one required report level will be simplified. The structure proposed in the NPRM reduces the number of voluntary functions (A-level), expense object classes, and revenue object classes by over half.
- Beginning in the 1991 report year, reporters who received FTA MIS grants will be able to report at either the voluntary or required level. FTA will continue to encourage voluntary reporting for large operators and will make these additional details easily accessible as an incentive for operators to contribute to the national data base.

Few of the 26 NPRM comments directly addressed reporting levels in general or in detail. Of the three respondents opposed to the NPRM proposal, two supported a single required level, and a third supported either one or two required levels. Fifteen rspondents either explicitly supported the proposed approach to reporting level or supported the overall NPRM structure but did not directly refer to reporting levels—probably the major proposed structural change.

Frequency of Reports

Far more respondents supported continuation of annual reporting than the proposed less frequent reporting. A few respondents suggested less frequent reports from operators with small fleets. In response to this clear consensus, FTA will continue annual reporting while easing the burden of reporting by reducing the number of required forms.

Method of Preparing Reports

In the case of multimode operators, operating expenses, operators' wages, labor years, ridership, and type of service are reported separately by mode. Operating expenses reported separately by function (operations, vehicle and nonvehicle maintenance, and administrations) are reported by mode. However, operating expenses that are reported by object class (e.g., wages, contracts, and fuel) are not reported separately by mode.

Comments overwhelmingly supported continuing the current structure of modal separation. At least as many respondents favored adding to modal data as reducing them.

Demographic Data: Revision or Expansion?

Each reporting agency has been required to submit a statement from the local metropolitan planning organization (MPO) stating the agency's service area and population and describing the methods used to determine the service area. FTA assigns a single census-defined urbanized area code (UZA), with population and surface area, to each reporter. This code, which is used to apportion Section 9 funds, can be an inaccurate measure of service area and population.

Respondents generally supported continuing to report or expanding demographic data. FTA proposes to eliminate the MPO statement but to continue collecting data on service area population and density. Because census data provide an inaccurate measure of service area and population, these data are not a good substitute.

PROPOSALS TO CHANGE DETAILED STRUCTURE

This section presents the proposals made in the NPRM to modify specific components of the systems and related issues.

Reducing Voluntary-Level Details

In restructuring and simplifying the number of voluntarily reported expense and revenue details, FTA's intent is to carefully balance the burdens of reporting against any losses of valuable data for analysis and historical continuity. FTA developed the following criteria to consolidate the number of current voluntary details into a simplified new structure.

- Consolidate minor cost items (in terms of dollars and reporters providing that item);
- Disaggregate large items;
- Retain easy-to-collect items;
- Avoid irrelevant or analytically meaningless items;
- Retain items that are key decision variables; and
- Avoid realignments from one category to another in the interests of preserving the continuity of 12 years of historical data.

Purchased Transportation Services

Transportation service provided under contract is described on several reporting forms. Form 002 describes contractual relationships. Costs of contracts are reported as expenses on the 300-series forms. Complete reports must be filed by or for contractors that provide over 50 revenue vehicles. A public agency contracting for under 50 revenue vehicles also describes contract service on separate Forms 004 (Maximum Service Vehicles) and 408 (Revenue Vehicle Inventory) for vehicles operated, 403 (Transit Way Mileage), and 406/407 (Transit System Service) for service supplied and ridership.

The threshold for submission of a separate Section 15 report by a purchased transportation provider is being increased from 50 to 100 vehicles in maximum service. This change is consistent with FTA's objective of easing the reporting burden for small transit agencies and operators.

Capital Expenses

The reporting system collects a limited amount of information on capital expenses in relation to the detail provided on operating expenses. Capital expense information includes a balance sheet (Form 101) with basic financial information on assets, liabilities, and capital at the end of the financial year. Rolling stock, facilities, and equipment are combined into a single category. Unlike operating expenses, which are structured to allow modal separation of costs, capital accounts are not separated by mode.

In addition, a single depreciation figure for all modes combined is reported on the expense forms (300 series) without separations identifying depreciation of vehicles or other assets by mode. The accounting system does not provide or recommend standardized approaches to depreciation or require reporters to identify the approaches they use. The amount and source of public assistance funds dedicated to capital are also identified for all modes.

It is possible that the lack of capital cost data encourages overemphasis on operating costs in analyses of performance and alternative investments and may also limit thorough evaluation of all expenses, revenues, and outputs. Capital expense data can include purchases and depreciation of capital assets, including rolling stock, plant, or other equipment.

Comments generally recognized the importance of capital information in the national reporting system and of adding annual sources and uses of capital to improve the usefulness of the data base. Of the 15 respondents requesting an expansion of capital information, 9 supported the addition of sources and uses of capital. Of the seven respondents requesting that the balance sheet be eliminated as inconsistent, four proposed adding sources and uses of capital.

FTA proposes to revise capital data reporting to add sources and uses of capital, as proposed by APTA. A new form will combine current information on private and public sources of revenues for capital with new information on uses of capital. Uses of capital will identify purchases of rolling stock; transit way, structures, and equipment; passenger facilities; land; and other assets. This new information, which was supported by industry and respondents, should provide valuable information for analysis without significantly adding to the reporting burden. All major categories for use of capital will be identified by mode.

To compensate for any additional effort in reporting uses of capital, FTA will eliminate the balance sheet. Although there is some support in the industry to retain it, because it is often reported inconsistently, the balance sheet of reduced value for analysis. Only one NPRM comment supported retaining the balance sheet.

Revenues

Information on revenues is reported in several categories. The required level Form 201 (Operating Revenue) contains information on fares, other earnings, and federal, state, and local grants, and identifies total subsidies for handicapped, senior, and student passengers combined. Form 202, used by all voluntary-level reporters, expands the Form 201 structure into greater detail. For example, Form 202 expands the single-fare total on Form 201 into seven categories. Forms 201 and 202 identify revenues for publicly operated, but not contracted, service. Multimode operators provide only systemwide totals, even though all reporters have the option of separating fares by mode.

Forms 103 (Capital Funding) and 203 (Sources of Operating Funding) describe revenues for operating and capital assistance by governmental source (federal, state, and local) and by the means used to collect revenues (e.g., sales, income, and gasoline taxes and tolls).

FTA proposes to replace the current single voluntary and required revenue reporting forms with a simplified structure and reduced details. The new structure will be the result of applying the criteria previously described.

Seven ANPRM and NPRM respondents proposed adding modal separation of fare revenues, whereas three opposed this separation. Although the voluntary- or required-level reporters have had the option of allocating fares by mode since the 1984 report, few have done so despite the fact that most operators collect this information for their own use. Few analysts have used modal fares, primarily because these fares are available only on tapes.

FTA recognizes the high level of interest by analysts in modal splits of fares, that would allow Section 15 data to be used to analyze a broad range of valuable modal performance measures, including farebox recovery rates, average fares, and subsidies per rider. FTA will not require modal fares because of the difficulty this type of system would present for operators with large numbers of transfers and monthly or other passes. However, FTA proposes to encourage a greater degree of reporting of modal fares and improving access to modal fares through published reports and microcomputer files.

Operating Expenses

Transit systems use the 300-series forms to report operating expenses in function (operations, vehicle and nonvehicle maintenance, and general administration) and object class (wages, fringe benefits, and other) categories. A reporter at the minimum or required (R) level uses the basic 4 functions and 14 object classes. This detail expands, for operators at any of the 3 voluntary levels, up to 44 functions and 47 object classes at the most detailed A-level. Voluntary expense details are consolidated to the required level in the annual report and on the Section 15 diskettes. Complete expense information is available on computer tape only.

Functions and object classes can be cross-classified, allowing, for example, identification of fringe benefits paid to vehicle operators. There is, however, limited ability to separate modal costs for multimode operators. Modal costs can be separated by function (e.g., light-rail vehicle maintenance) but usually not by object class (e.g., light-rail wages) or by function and object class (e.g., light-rail operators' wages).

There was a large range of views on voluntary reporting, the number of reporting levels, and the number of details in each level. Of the six ANPRM respondents who supported voluntary reporting, three supported retaining the current system and two proposed a reduced level of voluntary details. Of the 22 respondents supporting all required reporting, 9 supported use of the current required level alone, 1 recommended that the current B-level be used for all reporters, 10 proposed two required levels, and 1 each supported three and four required levels.

FTA proposes to replace the current expense reporting structure of three voluntary and one required level with a simplified structure and reduced details. This new structure will be the result of applying the criteria previously described.

FTA proposes to realign the Uniform System of Accounts and to move Ticketing and Fare Collection (151) and System Security (161) from the General Administration to the Operations category. These functions are major cost items for current A-level reporters and represent the fourth and fifth largest cost items of the 44 reported. Realigning these costs could disrupt the continuity of 12 years of historical costs, because the definitions and values of Operations and General Administration will change. However, there is a logic to moving these items into operations.

As previously discussed in structural issues, few of the 26 NPRM comments dealt directly with expense reporting levels or the number of details. Of the three respondents opposing the proposed approach to reporting levels, two supported a single required level, and a third supported either one or two required levels. Fifteen respondents either explicitly supported the approach to reporting levels proposed in the NPRM or supported the overall NPRM structure but made no direct reference to reporting levels—probably the major feature of the proposed structure. There were only two comments addressing the proposed realignments—both in support.

Other Financial Data

Operators' Wages and Hours Schedule

The current Form 321 (Operators' Wages) provides a detailed breakdown of the hours and wages paid to revenue vehicle operators, including major categories of dollars and hours for both operating and nonoperating paid wages. Seven respondents requested either eliminating the Operators' Wages and Hours Schedule or consolidating the detailed categories. FTA proposes to simplify the Operators' Wages and Hours Schedule by consolidating detail and providing improved definitions.

Fringe Benefit Contributors

Fringe benefit contributors of both employers and employees are reported on Form 331. Of five respondents proposing a revision to fringe benefit reporting, four suggested eliminating employee contributions. FTA will eliminate reports of employee contributions to fringe benefits. This change is consistent with the specific comments received on fringe benefits and with the general support for simplifying reporting.

Pension Plans

Information on the cost components of the various pension plans that reporters provide for their employees has been reported on Form 332 but has not been published. Respondents universally supported elimination of the pension plan data. Although 20 supported elimination of Form 332, 1 respondent supported consolidation, and no other respondents defended the data for analysis.

FTA proposes to eliminate the pension plan questionnaire. This change is consistent with the comments on the minimal value of pension data and the general support for simplifying reporting and reducing the number of forms. The total cost of the pension plan will continue to be a part of, and included with, the fringe benefit cost.

Nonfinancial Operating Data

The reporting system uses several forms to collect information on a broad range of nonfinancial characteristics of transit service, including maintenance of vehicles, fleet inventories, infrastructure, labor resources, safety, service supplied, and ridership.

Fleet Inventory

The reporting system records several types of fleet information on several forms. Forms 003 and 004 (Maximum Service Vehicles) contain the number and type of vehicles required and available, measured at the time of year when maximum service occurs, to meet peak or maximum service requirements. Forms 406 and 407 (Transit System Service) record the number of vehicles in operation during average daily time periods. Form 408 (Revenue Vehicle Inventory) measures all vehicles in the total fleet, including those that are active, stored, and awaiting sale.

Consistent with numerous ANPRM responses requesting simplification of reporting and reduction in the number of forms, FTA is eliminating Forms 003 and 004 (Maximum Service Vehicles) by incorporating the information from those forms onto Forms 406 and 407 (Transit System Service).

Service Periods

Periods of transit service for each mode, including a.m. and p.m. peaks, midday, and hours of service for weekdays, Saturdays, and Sundays are reported on Form 401. These data are not published in the Annual Report.

The great majority of respondents recommended eliminating Form 401. Consistent with numerous ANPRM requests to simplify reporting and reduce the number of forms, FTA is eliminating Form 401. Information on service period schedules will be incorporated onto Forms 406 and 407 (Transit System Service).

Service Reliability (Roadcalls)

Data on roadcalls for mechanical failure and other reasons are reported on Form 402. The ANPRM asked whether reports of roadcalls are of value, whether definitions should be revised to make the data more useful, or whether alternative data items could be substituted to measure reliability.

Taken as a group, the ANPRM and NPRM comments expressed a high level of dissatisfaction with the current approach to reporting roadcalls. Because roadcalls are a crucial aspect of performance, the current definition of roadcalls will be retained until FTA and the industry are able to develop a superior standardized measure of reliability.

Transit System Employee Counts

Systemwide hours worked are categorized by various functions on Form 404. These hours are divided by 2,080 and reported as full-time equivalents (FTEs). There are no distinctions between labor of full- and part-time employees.

Some respondents supported reporting work hours instead of annual FTEs, arguing that the use of 2,080 h/labor-year is arbitrary and confusing. A few respondents supported the use of percentage of hours worked by part-time employees as a useful indicator of the extent to which part-time employees are used.

To avoid the arbitrariness of the current definition of FTE employees, FTA proposes the use of work hours instead of equivalent work years as the standard measure of labor equivalents. A check-off box will be added to Form 404 to indicate the use of part-time operators. In addition, on a trial basis, all reporters will have the option of indicating the percentage of paid hours for revenue vehicle operations provided by part-time operators on Form 404. The local definition of part-time will be summarized on Form 005 (Supplemental Information). FTA believes that these data will be valuable in assessing the effect of part-time labor on performance, including costs, service, safety, and other factors.

Service Supplied and Consumed

Information on service supplied and consumed is reported on Form 406 for nonrail modes and on Form 407 for rail modes. Information includes measures of the quantity of service supplied, including vehicle miles and hours, actual and scheduled vehicle revenue miles, and capacity miles; and unlinked passenger trips and passenger miles. Most items on these forms are reported by time of day.

Two comments opposed and no comments supported development of new measures of service quality. Although it will not add measures of service quality, FTA will improve the access to reports of actual and scheduled vehicle revenue miles that are currently being reported. Scheduled vehicle revenue miles are currently available only on tape. Comparisons of actual and scheduled vehicle revenue miles can provide a measure of one aspect of service reliability.

SUMMARY OF PROPOSED OPERATIONAL IMPROVEMENTS

On the basis of comments from the rulemaking process and the industry Section 15 advisory groups, FTA is undertaking extensive operational improvements to the program. The purpose of these improvements is to ease the burden of reporting and improve the usefulness of the data base. The simplified and rationalized content and structure of the systems and streamlined reporting procedures will improve the quality of the data base and provide the foundation for the next stage of the Section 15 program: emphasis on improved data applications by all industry groups.

FTA has implemented several procedural changes that will ease reporting. The requirement for a full report for contract service will be raised from 50 to 100 vehicles in maximum service, substantially reducing the burden for reporting on the growing number of contract services.

FTA will waive specific reporting requirements that are particularly burdensome for small reporters. Reporters operating 25 or fewer revenue vehicles currently are not required to provide data on operator wages, fringe benefits, and pension plans. In addition, sampling or other procedures that meet prescribed precision and confidence levels need only be applied every third year by reporters that (a) serve urbanized areas with populations less than 500,000; (b) directly operate fewer than 100 revenue vehicles for all modes in maximum service; or (c) use purchased transportation services (private or public carriers providing transit service under contract to a public agency, except those purchased transportation services submitting separate Section 15 reports).

FTA will rewrite program documentation to accommodate the structural changes resulting from the rulemaking and to update and clarify definitions of terms. The original documentation on the systems (*8*) will be rewritten, and the *Reporting Manual* (*9*) will continue to be updated each year.

In response to requests for streamlined reporting and improved data access, FTA will develop software to allow reporters to perform basic validation checks before filing reports on diskettes. This procedure will provide reporters with their own data in machine-readable form. Respondents enthusiastically supported development of this capability.

FTA will take several steps to improve the usefulness of the data base to industry analysts. The *Data User's Guide to the FTA Section 15 Reporting System* (*10*) will be updated to document changes from the rulemaking and will help data users identify and apply required data, particularly for time-series analyses.

FTA will improve data applications through new means of computerized access and production of new products. All data submitted by reporters currently are stored on magnetic tapes available for public use. Currently, only a subset of the complete data base containing some, but not all, required-level data is published in the annual report and distributed on diskettes for use in spreadsheets. Much of the revenue and financial details provided by voluntary-level reporters and some required-level details, including operator time and fleet inventories, are available only on tape and must be run on mainframe computers.

According to the comments, the tapes discourage applications of the unpublished data. Respondents also requested better automated access to the data base through new computer formats or on-line access. To improve access, the entire data base defined in the final rule will be accessible to the public for use on microcomputers running standard spreadsheet and data base software. Beginning with the 1990 data base, all operating expense and revenue data, including that previously available only on tape, will be available for microcomputer applications.

Beginning with the 1991 report year, FTA will produce several new reports: transit profiles for individual reporters, with key data items, performance measures, and graphic displays, grouped by the 30 largest operators (*11*), operators serving urbanized areas of more than 200,000 (*12*), and operators serving urbanized areas of fewer than 200,000 (*13*); a new annual report of national summaries and trends (*14*); and a new annual data table report (*15*). To ease the transition to the restructured system, FTA will continue to provide training for reporters and will develop training and guides to encourage applications of the data base.

Although completion of the rulemaking will represent a major stage in the evolution of the Section 15 program, improvements will continue to ease reporting and encourage data applications. The mechanisms for these ongoing improvements will continue to be the *Reporting Manual*, published annually. FTA will continue to respond to the concerns of reporters and data users and will work cooperatively with APTA, TRB, and other industry groups to ensure that the Section 15 program realizes its potential as a vital resource to the industry.

REFERENCES

1. W. M. Lyons. An Analysis of Nine European Public Transit Data Bases—Insights for the FTA Section 15 Program. In *Transportation Research Record 1144*. TRB, National Research Council, Washington, D.C., 1988, pp. 24–33.
2. Comparison of Absolute Subsidy Levels Between Urban Public Transport Systems in Lyon, Tyne and Wear, Madrid, and Rotterdam. Presented at European Conference of Ministers of Transport, Paris, France, 1989.
3. W. M. Lyons. An Overview of Light Rail Systems. Presented at European Conference of Ministers of Transport, Paris, France, Oct. 1989.
4. FTA Section 15 Advisory Committee. Final Report to the Administrator on the Quality and Usefulness of the Nation's Mass Transportation Data Base. FTA, U.S. Department of Transportation, Sept. 1986.
5. Proposal to Change the Section 15 Uniform System of Accounts and Records and Reporting System. American Public Transit Association, 1988.
6. *Uniform System of Accounts and Records and Reporting System; Advanced Notice of Proposed Rulemaking.* 55 Fed. Reg. 33,078 (1990) (Codified in 49 C.F.R. Part 630).
7. *Uniform System of Accounts and Records and Reporting System; Notice of Proposed Rulemaking.* 56 Fed. Reg. 38,256 (1991) (codified in 49 C.F.R. Part 630).
8. *Urban Mass Transportation Industry Uniform System of Accounts and Records and Reporting System*, Vol. 1 (General Description) and Vol. 2 (Uniform System of Accounts and Records). FTA, U.S. Department of Transportation, Jan. 1977.
9. *Reporting Manual for the 1991 Section 15 Report Year.* Audit Review and Analysis Division, Office of Capital and Formula Assistance, FTA, U.S. Department of Transportation, April 1991.
10. *Data User's Guide to the FTA Section 15 Reporting System.* Volpe National Transportation Systems Center. U.S. Department of Transportation, Cambridge, Mass., June 1989.
11. *Transit Profiles for the Thirty Largest Agencies for the 1990 Section 15 Report Year.* FTA, U.S. Department of Transportation, Nov. 1991.
12. *Transit Profiles—Agencies in Urbanized Areas Exceeding 200,000 Population for the 1990 Section 15 Report Year.* FTA, U.S. Department of Transportation, Nov. 1991.
13. *Transit Profiles—Agencies in the Urbanized Areas with a Population of Less Than 200,000 for the 1990 Section 15 Report Year.* FTA, U.S. Department of Transportation, Nov. 1991.
14. *National Transit Summaries and Trends for the 1990 Section 15 Report Year.* Report UMTA-MD-08-9009-91-4. FTA, U.S. Department of Transportation, Dec. 1991.
15. *Data Tables for the 1990 Section 15 Report Year.* FTA, U.S. Department of Transportation, Dec. 1991.

DISCUSSION

JOEL MARKOWITZ
Metropolitan Transportation Commission, 101 Eighth Street, Oakland, Calif. 94607.

Lyons and Fleischman describe the pending changes in the federal transit reporting system—changes that should provide a strong foundation for further improvements in the accuracy, timeliness, and relevance of this vital national data base. This discussion explores some of the issues raised by the agencies responsible for submitting the Section 15 reports.

In May 1983, APTA formed a special committee to analyze problems in the Section 15 system and propose solutions. APTA completed its review in 1988, delivering a complete set of recommendations to UMTA (not FTA).

The draft federal proposal (*7*) was a pleasant surprise for the APTA committee members who had been promoting their recommendations over the years. As Table 1 indicates, many of the significant APTA committee recommendations were addressed in the draft rule. The only significant issues raised by the committee over the draft are described in the following.

SIGNIFICANT ISSUES

Voluntary Reporting

The APTA committee believes that a voluntary reporting level is inherently inconsistent with the central goal of a comparable, relevant, and complete national data base. Any analyst attempting to use voluntarily reported data is faced, by definition, with a nonrepresentative sample, the analysis of which is necessarily incomplete and ambiguous and cannot be generalized.

Reporting of Flawed Data

The committee strongly believes that it is better to have gaps in the historical data base than to maintain data known to be wrong, misleading, or useless. Even though a data item might be desirable, if it cannot be rigorously defined and accurately collected, it should not be reported. This long-standing debate is summarized in the two slogans of the opposing players: "Some data are better than no data!" versus "No data are better than bad data!" In the APTA committe's view, two

TABLE 1 APTA COMMITTEE RECOMMENDATIONS VERSUS FEDERAL DRAFT RULE

APTA Committee Recommendation	FTA Response
Forms 001-006	
Drop Forms 003-004	Done
Clarify MPO data	?
100- and 200-Series forms	
Drop balance sheet	Done
New capital form	Under development
Reduce revenue detail	?
Maintain voluntary modal fares	Done
300-Series forms	
Correct ticketing and security	Done
Drop employee benefit contribution	Done
Drop pension form	Done
Simplify 321 (wages)	Under development
Clarify joint expenses	?
Break out propulsion power	?
Align taxes with expense	?
400-Series forms	
Drop 401	Done
Drop passenger miles	No
Drop capacity miles	No
Drop roadcalls	No
Use labor hours, not FTEs	Done
Revise accident form	?
Reduce 406 data	?
Add fleet summary	No
General	
Eliminate voluntary	No
True "voluntary"	Done
Increased training	Done
Increased automation	Under development
Improved access to data	Under development
Ongoing improvement process	?

Done = Included in latest federal draft rule (NPRM).
? = Not clear how issue was addressed.
No = Appears to have been rejected.
Under development = FTA commitment to pursue further but specifics unknown.

items remaining in the NPRM fall under the latter category: capacity miles and roadcalls. These data are inconsistently reported, they lack comparability across operators, and they lead to erroneous or meaningless conclusions.

Specific Forms

Form 001 (Identification)

Form 001 is where FTA proposed to include data on service area population and land area (*7*, p. 38259). However, the proposed elimination of a separate MPO statement brings into question the lack of consistency in definitions and methods around the country. The lack of standardized procedures will lead to noncomparable and therefore unusable statistics. The purpose of these data was to allow a basis to normalize some information per capita or per square mile. With no consistency established, such comparisons will be meaningless.

Form 321 (Operator Wages)

FTA has agreed to simplify the overly detailed operator wages form (*7*, p. 38261) but did not elaborate. This can be a very difficult form to complete, depending on the specifics of internal payroll systems and labor contract provisions. The committee spent considerable effort developing its 1988 proposal for this form to reflect a useful level of detail while recognizing practical limitations in achieving consistency.

Accident Form (405)

The introduction of a new Form 405 in the 1990 manual resulted in great confusion among reporters and will probably result in an inconsisent and incomplete 1990 submission. The original form needed improvement, but a revised form needs to be more thoroughly thought through and tested. The APTA 1988 proposal includes a simplified form that clarifies data on the previous FTA form but does not address the same concerns contained on the newer FTA form.

Form 406/407 (Service Supplied and Consumed)

APTA's members repeatedly stressed that forms 406 and 407 can take as much effort to complete as all the financial forms combined. The 1988 proposal recommended that the two forms be combined and that unnecessary details be eliminated. The NPRM Table 7 on Operating Data Elements (*7*, p. 38272) and the discussion on page 38262 appear to continue the same level of detailed reporting as in the past. In addition, the discussion recommends using a ratio of actual versus scheduled data as a measure of service quality. The APTA committee believes both positions to be mistaken.

The committee believes that its 1988 proposal would save valuable operator staff time and cost, while providing more useful and relevant data for analysts. Although APTA supports the pursuit of research into appropriate measures of service quality, the FTA proposal will not serve the desired end. Deviations of actual from scheduled miles can be caused by any number of operational reasons, reflecting little or nothing about service reliability. The right performance measures should go into Section 15, but there is no useful purpose in promoting the wrong measures.

Form 408 (Vehicle Inventory)

In addition to deleting "Standing Capacity" and "Average Lifetime Mileage," the 1988 APTA proposal recommended adding a new fleet summary form to explicitly clarify the vehicle classifications by ownership and usage. The new form was intended to eliminate the confusion over varying definitions of fleet size and spare ratios and is still needed.

Other Issues

Training

FTA's new commitment to Section 15 user training is encouraging. More workshops should be scheduled in more locations to reduce the travel burden.

In addition to user training, some attention should be given to training for auditors, many of whom have few transit clients and little familiarity with the transit industry. This type of training will help avoid future reporting problems.

More should be done to reduce, consolidate, and simplify the amount of reference documentation that Section 15 reporters are expected to have on hand. Manuals, notices, circulars, and other reports comprise a daunting library that is difficult to use when seeking answers to typical questions. It may be possible in the future to have on-line help as an adjunct to the proposed computerization of the input procedure.

Automation

FTA's desire to make better use of readily available personal computer hardware and software throughout the Section 15 system is an excellent idea that APTA strongly supports. On-screen data entry with self-validation checkes will ensure more accurate submittals, will cut down on the need for the validation contractor to correct problems, and will surely speed production of the annual data compilation. Publication of the data in diskette form will make the information more readily accessible to typical data users.

FUTURE ENHANCEMENTS

More important than all the specifics on forms and definitions is FTA's commitment to annual review and improvement to the Section 15 system (*7*, p. 38257). The proposed "reasonable notice" definitions (*7*, p. 38263) will place a premium on getting expeditious input from the transit community on any revisions. To continue the great progress the NPRM represents, FTA should consider how to best establish a process for ongoing consultation with reporters and users. FTA should continue to discuss any future Section 15 revisions with representatives of the industry and users on an ongoing basis. This is the best way to ensure the continuing improvement of this vital national information resource. The method chosen is unimportant. The important point is that ongoing improvements require the active participation of those closest to the data. Industry and TRB representatives should be eager to work with FTA to facilitate such a process.

Publication of this paper sponsored by Committee on Transit Management and Performance.

Measuring Cost-Effectiveness of Rail Transit Projects

R. S. MARSHMENT

UMTA evaluates the cost-effectiveness of competing rail transit projects by using an index proposing to measure the average cost per new rider of shifting from all-bus service to rail transit. The unusual manner in which costs and benefits are measured and included in the UMTA cost-effectiveness formula prompts this investigation of the ability of the index to identify desirable projects when the selection criterion is an excess of benefits over costs. The methodology uses 10 economic assumptions and an investment model for evaluating rail projects. Using the model, the UMTA cost-effectiveness index and an alternative index incorporating nonuser benefits are computed for three projects. By ranking the projects according to the net benefits they generate, the UMTA index is shown to be an unreliable indicator of economic efficiency.

UMTA is charged under Section 3(i) of the Urban Mass Transportation Act of 1964, as amended, with assisting in the development of those fixed guideway mass transit projects that are demonstrated through the evaluation of alternatives to be cost-effective. This legislative mandate acknowledges UMTA's practice, instituted in 1984, of requiring urban areas seeking federal financial assistance for rail transit projects to employ standardized planning practices and measures of costs and benefits. UMTA maintains that cost-effectiveness computed according to its protocol is a valid indicator of project merit when the comparison is among rail projects proposed by various urban areas.

The UMTA cost-effectiveness index can be approximately described as the annualized average cost per new transit rider attracted by a rail investment compared with improved bus service. UMTA prefers projects with cost-effectiveness indexes less than $6.00. Projects meeting this threshold and passing other environmental and financial tests are permitted to advance toward construction. Congress renders final judgment on project financing and has modified UMTA staff recommendations from time to time (*1*).

The need for criteria by which to judge the merits of competing fixed guideway projects is obvious. Nevertheless, many criticisms have been leveled against the UMTA cost-effectiveness index. Some of this criticism concerns perceived inequities in the way UMTA requires certain computations to be performed and costs and benefits measured (*2,3*). UMTA admits to interpretation difficulties when the index takes on negative values and when there are high-occupancy vehicle components in a project (*4*). This paper suggests that many of the problems with the UMTA index can be traced to its initial improper specification. By close examination of the assumptions underlying UMTA's cost-effectiveness index, the measure can be shown to be an ambiguous indicator of project merit that potentially leads to inferior project selection.

Division of Regional and City Planning, University of Oklahoma, Norman, Okla. 73072.

UMTA COST-EFFECTIVENESS INDEX

UMTA describes the method of computing the cost-effectiveness index in draft guidelines published in 1986 (*4*). Equation 1 summarizes the calculation that is made for a single year at the end of a 15-year period.

$$CEI = \frac{\Delta\$CAP + \Delta\$O\&M - B(v_b)}{\Delta v} \quad (1)$$

where

$$\Delta\$CAP = \$CAP_r(v_r) - \$CAP_b(v_b) \quad (2)$$

$$\Delta\$O\&M = \$O\&M_r(v_r) - \$O\&M_b(v_b) \quad (3)$$

$$B(v_b) = \$TT_r(v_b) - \$TT_b(v_b) \quad (4)$$

$$\Delta v = v_r - v_b \quad (5)$$

and

r = the fixed guideway alternative,
b = the best all-bus alternative,
$\$CAP$ = annualized capital cost,
$\$O\&M$ = annualized operating and maintenance cost,
$\$TT$ = travel time cost,
B = user benefits, and
v = annual patronage.

All cost terms in Equation 1 are annualized 1-year totals expressed in current dollars.

UMTA imposes strict guidelines on the number and type of engineering studies that must be performed to develop cost estimates and patronage forecasts (*5*). For example, estimates of capital, operating, and maintenance costs must be developed in parallel with patronage forecasts to ensure a minimum-cost solution. This requirement justifies expressing the cost terms in Equations 2 and 3 as functions of passenger volumes. Benefits to travelers who would patronize the bus alternative are measured in dollars and weighted by trip purpose and are included in the numerator of Equation 1 as an offset to sponsor costs.

UMTA specifies that at least three alternatives be examined in a fixed guideway study: (a) the no-build plan; (b) a transportation system management (TSM) plan; and (c) the fixed guideway alternative(s). The no-build alternative serves as the benchmark for assessing the social and environmental consequences of the proposed action but is not involved in determining cost-effectiveness, which is computed by comparing the TSM and fixed guideway alternatives. The TSM plan allows for significant improvements in corridor transit service using only existing infrastructure, that is, without construction of a new transit guideway. The TSM plan represents the best all-bus program of service and facility improvements and is identified as the bus alternative in Equations 2 through 5. Compared with rail transit investments, TSM plans will be relatively low cost, emphasizing demand management and operational strategies.

ASSUMPTIONS

Projects generating benefits that exceed costs are economically efficient and may warrant investment. Strict application of this economic efficiency test to rail transit investments is not practical given current capabilities to forecast benefits for the life of durable rail transit lines (*3*). As a compromise, the UMTA cost-effectiveness index is computed by using annualized costs and predicted annual patronage 15 years in the future.

Technical limitations in forecasting patronage and calculating benefits cannot be resolved in the short term. Consequently, to develop a mechanism for ranking competing projects that depends on an economic efficiency criterion, UMTA has made nine simplifying (and unstated) assumptions:

1. There are economically efficient projects in which to invest;
2. TSM investments are always economically efficient;
3. Conditions in a single horizon year represent conditions for all previous and subsequent years;
4. The price of travel equals marginal user cost;
5. There are scale economies in corridor transit service;
6. Transit demand is downward sloping and linear;
7. Nonuser benefits vary directly with changes in transit patronage;
8. Work-trip travel time savings are twice as valuable as non-work-trip savings; and
9. The value of travel time does not vary with income.

Assumption 1 is justified by the willingness of all levels of government to spend money on rail mass transit projects. The effect of Assumption 2 is to require that rail transit investments provide more net benefits than a lesser investment in expanded bus service. UMTA reasons that the TSM plan, rather than the no-build alternative, is the best benchmark for comparison because the benefits and costs of the build alternatives are better isolated.

In many cases, the TSM alternative presents an opportunity to identify improvements that are desirable today. Therefore, potentially large benefits are available from making changes in a do-nothing alternative that is largely based on today's situation. Because these benefits are independent of any major investment, they should not be attributed to the guideway options. This miscounting of benefits cannot be avoided if the do-nothing is used as the baseline since the average measures of cost-effectiveness would include the benefits of the TSM improvements over the do-nothing alternative. This problem is avoided if the TSM alternative serves as the baseline because the benefits produced by the TSM actions do not enter into the calculations (*4*).

Assumption 3 is not compelling, since patronage growth can vary from area to area. The alternatives to this assumption are not appealing: (a) develop models to predict patronage in each year for the life of the project; (b) interpolate between two or more patronage forecasts; or (c) delete user benefits from the cost-effectiveness assessment.

UMTA's insistence that unit operating and maintenance costs be minimized for a given level of demand, a process known as equilibration, justifies the assumption of marginal-cost pricing (Assumption 4). In practice, the UMTA methodology results in passengers paying a marginal user cost.

Assumption 5 indicates that average costs are falling over the range of patronage volumes at which new rail transit lines operate. The need for public subsidies to construct and operate rail transit is well documented, which supports a low-demand investment environment (*6*). A downward sloping demand curve (Assumption 6) is the standard assumption, although the specification of a liner relationship is a computational convenience.

Assumption 7 has not been empirically substantiated but appears to have some merit (*7*). Auto trips diverted to transit do generate nonuser benefits, such as air quality improvement, energy savings, and congestion reduction. It is less clear that the change in transit volume is the proper indicator of these nonuser benefits. Assumptions 8 and 9 are used to establish the dollar value of user benefits (*8*).

EVALUATING BUS AND RAIL TRANSIT INVESTMENTS

To be funded by UMTA, a proposed rail transit investment should satisfy two criteria. First, the investment should be economically efficient, i.e., total benefits should exceed incremental costs. Second, because there may be more projects satisfying the first criterion than there is money, those projects generating the greatest surplus of benefits over costs should be funded first.

Congress has directed UMTA to assist in developing cost-effective fixed guideway transit projects because of a belief that there exist rail transit projects that produce total (user and nonuser) benefits higher than costs. Because few rail transit projects generate more user benefits than costs, a project must produce significant nonuser benefits to be economically efficient. But nonuser benefits are difficult to measure in dollar terms, and UMTA specifically proscribes their use in calculating cost-effectiveness.

UMTA incorporates nonuser benefits in its project evaluations in two ways. First, UMTA favors projects in which local financial participation in the capital cost exceeds the minimum required. The difference between the minimum required and the amount locally committed is regarded as the shadow price of nonuser benefits. The second method rests on the assumption that the principal means by which a rail project generates nonuser benefits is through diversion of auto

TABLE 1 ALTERNATIVE TRANSIT INVESTMENTS IN THREE CITIES

	Project					
	One		Two		Three	
	Rail	Bus	Rail	Bus	Rail	Bus
Volume (v)	39.39	20.00	59.00	44.00	67.29	61.79
Capital Cost ($)	40.00	10.00	40.00	10.00	40.00	10.00
Operating and Maintenance Cost ($)	17.83	21.71	20.11	33.45	20.50	35.97
Marginal Cost	0.09	0.43	0.08	0.12	0.12	0.27
Benefits to Existing Users ($)	6.73		1.66		9.03	
Benefits to New Riders ($)	3.26		0.28		0.40	
Cost Effectiveness (*CEI*)	1.00		1.00		1.00	
Cost Effectiveness (n)	4.95		52.57		12.75	

Costs and volumes in millions.

drivers to transit. Thus, the denominator in Equation 1, the number of new riders, does double duty. It measures a component of user benefits, namely, the number of new riders, and indirectly represents nonuser benefits, which is allowed by Assumption 7.

This method of incorporating nonuser benefits is cumbersome and unsystematic and rests on controversial assumptions about willingness and ability to pay. One particularly troubling feature of the UMTA procedure is the use of two different measures of benefits—the dollar value of travel time savings for one group and the number of new riders for the other. The more traditional approach is to value all benefits in terms of the value of the travel time savings (*9–11*).

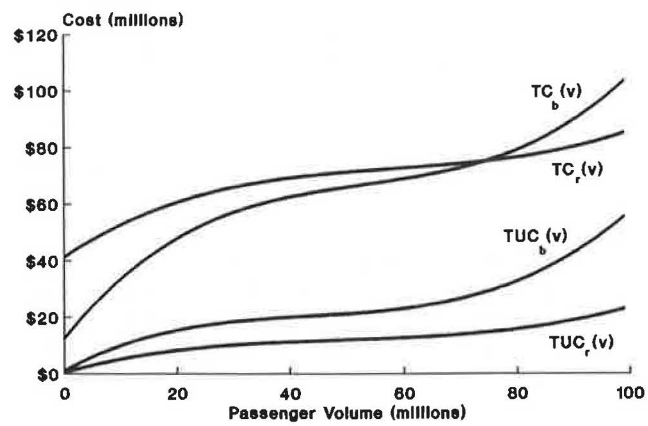


FIGURE 1 Long-run total and user cost model of corridor transit service.

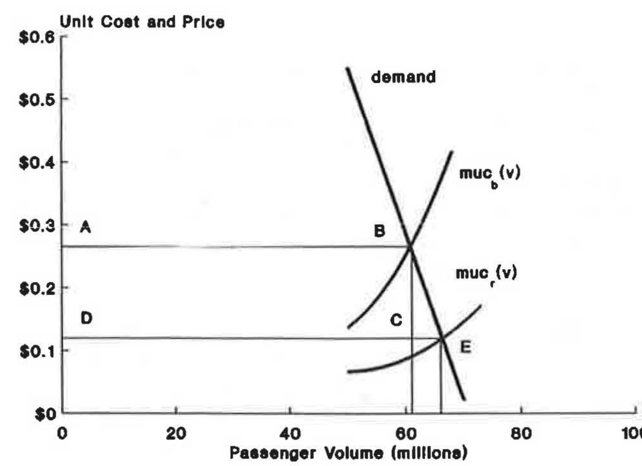


FIGURE 2 User benefits.

Calculating Cost-Effectiveness

The discussion that follows makes use of the variables already introduced plus the following nomenclature:

$TC_m(v)$ = the sum of the annualized capital, operating, maintenance, and user costs for a corridor public transportation investment ($m = r$ for rail and $m = b$ for bus) designed for volume v;

$TUC_m(v)$ = total user cost, obtained by subtracting capital, operating, and maintenance costs from total costs;

$TB_m(v)$ = the sum of the annualized benefits to patrons of the all-bus alternatives, $B(v_b)$, benefits to new riders, $B(v_r - v_b)$, and benefits to nonusers, $NB\ (v_r - v_b)$; and

$muc_m(v)$ = marginal user cost.

Equation 6 expresses Assumption 7 as a linear function of new rider benefits:

$$NB(v_r - v_b) = n[B(v_r - v_b)] \quad (6)$$

where n is a multiplier that links new rider and nonuser benefits.

Project 3 in Table 1 and the investment environment depicted in Figures 1 and 2 illustrate how UMTA computes cost-effectiveness. To be consistent with UMTA definitions, all costs in Table 1 and Figures 1 and 2 are 1-year annualized values and include a 10 percent return on investment. Because scale economies are assumed, only the portions of the curves in which average costs are falling are germane to the analysis. Two alternative investments are shown in Figures 1 and 2; one, an improved bus option and the other, a rail investment. All three projects in Table 1 were derived from the cost curves in Figures 1 and 2; note that the capital cost is the same for all project combinations, implying that all regions have the same construction and operating cost functions.

In Figure 1, $TC_r(v)$ is a flatter curve than $TC_b(v)$, reflecting the greater productivity of rail transit at high passenger volumes (*12–14*). The capital cost of the rail option is higher than the bus investment, as indicated by the larger *y*-intercept of the rail alternative. Total user costs, which are a component of total cost, are also shown.

Figure 2 is derived from Figure 1. Marginal user costs are the first derivatives of the total user cost functions in Figure 1. If demand is taken to represent marginal benefit, benefits to existing users $[B(v_b)]$ are the dollar value of the travel time savings resulting from the rail investment realized by patrons of the TSM option. For Project 3, Figure 2 depicts benefits to existing users as the rectangular area *ABCD*, which is equal to the marginal user cost savings per trip, resulting from the investment multiplied by the number of bus riders.

Although marginal user cost will not ordinarily be known, the difference between marginal user cost for the rail and bus alternatives can be derived from benefits to existing riders, which is known. Planning agencies estimate benefits to existing riders by summing the product of the number of TSM patrons and the travel time savings for each zone pair in which a change in travel time has occurred as a result of the proposed rail investment. These time savings are converted to dollar equivalent values by multiplying by the value of time for various trip purposes. Dividing the benefits to bus riders computed in this manner by the number of bus riders yields the difference in marginal user cost. In Figure 2, this value is equivalent to dividing the rectangular area *ABCD* by volume $v_b = 61.79$ million annual bus passengers.

The dollar value of benefits to new riders is the triangular area *BCE* in Figure 2, computed according to Equation 7.

$$B(v_r - v_b) = 0.5\,(v_r - v_b)\,[muc(v_b) - muc(v_r)] \quad (7)$$

The UMTA index is derived according to Equation 1. For Project 3, the calculation is

$$CEI = \frac{(40.00 - 10.00) - (20.50 - 35.97) - [(0.27 - 0.12)(61.79)]}{67.29 - 61.79}$$

After allowing for rounding, all of the projects in Table 1 have UMTA cost-effectiveness indexes equal to 1.0. On the basis of these indexes, UMTA should be indifferent about which of the projects to fund; all of the projects involve the same capital cost.

Incorporating Nonuser Benefits

Most interpretation problems with the UMTA index can be traced to the peculiar manner in which costs and benefits are commingled. To demonstrate this point, consider that the following inequality is a criterion for economic efficiency:

$$\Delta\$CAP + \Delta\$O\&M < B(v_b) + B(v_r - v_b) + NB(v_r - v_b) \quad (8)$$

Substituting Equation 6 into Equation 8 and solving for *n* yields

$$n > \frac{\Delta\$CAP + \Delta\$O\&M - B(v_b) - B(v_r - v_b)}{B(v_r - v_b)} \quad (9)$$

Assumption 1 establishes that there are economically efficient investments. Of these economically efficient investments, the minimally acceptable project has total benefits just equal to incremental cost. Assigning the value n^* to the multiplier for the minimally acceptable project, any other project that has a lower value of *n* would be preferable to a project whose multiplier is n^*, if to the nine assumptions already made a tenth is added:

10. The ratio of nonuser benefits to new rider benefits is the same for all rail projects.

For projects with $n < n^*$, the nonuser benefits that must be generated from new user benefits are fewer than the minimum necessary to make a project economically efficient. Stated differently, total benefits will exceed the incremental cost for projects with values of $n < n^*$.

The last row of Table 1 shows the effect of evaluating the three projects using *n* as an indicator of project merit. As is evident, Project 1 is superior to the others. If the multiplier for the minimally acceptable project is 12.75 (Project 3), the present value of the annual net benefits for Project 1 is found by setting *n* equal to 12.75, computing nonuser benefits according to Equations 6 and 7, and solving the inequality in Equation 8, yielding an excess of benefits over costs of $25.44 million.

FUTURE RESEARCH

Many elements of UMTA's methodology warrant additional research. Alternative cost-effectiveness indexes, such as *n*, may be more valid indicators of project merit than UMTA's cost-effectiveness index and should be field-tested. In connection with these tests, the implications of relaxing UMTA's second assumption should be investigated. Because some rail projects are superior to all-bus systems involving smaller investments, it seems reasonable that only those rail projects demonstrated to be more cost-effective than their TSM benchmarks should compete for UMTA funding. The incremental value of *n* computed from a TSM benchmark could still be used to rank projects, but grant applications might be limited to those rail projects with values of *n* less than the TSM option computed from a no-build benchmark.

Assumptions 7 and 10 are critical to justifying rail transit investments using economic criteria; however, the relationship between benefits to new riders and those for nonusers is poorly understood. In this discussion, the relationship has been treated as linear and multiplicative. Other models might be more appropriate. The emotional debate over rail transit projects is largely a disagreement over the extent of positive and negative externalities. This is an area clearly in need of additional investigation.

Because Assumptions 8 and 9 may involve significant project biases, a consensus on assigning dollar values to travel time must be reached. Failing this consensus, a different philosophy of project evaluation will be necessary.

CONCLUSION

Viewed in the context of traditional measures of project benefit, the UMTA cost-effectiveness index cannot be readily interpreted. By measuring benefits in two different units, no estimate of total benefits can be obtained, preventing a finding of economic efficiency. The UMTA index also treats the benefits of one group as more important than another, inappropriately incorporating distributional impacts in the calculus. For existing riders, benefits are measured in travel time savings and offset sponsor costs in the numerator. For new riders, benefits are measured in terms of trips, making the UMTA index highly sensitive to changes in patronage, and encouraging the attraction of new riders, regardless of trip length, as the principal design goal.

This paper proposes an alternative cost-effectiveness measure that is more consistent with cost-benefit analysis theory and that explicitly and systematically incorporates nonuser benefits. The alternative cost-effectiveness index (n) represents the amount of nonuser benefit required to make rail investment benefits equal to cost. The index n can be calculated from data ordinarily produced in rail transit investment studies, and so it does not pose an additional data collection or computational burden. However, project rankings would be affected if n were substituted for UMTA's cost-effectiveness index as the design objective shifts from attracting new riders to generating benefits to new riders.

ACKNOWLEDGMENT

The author would like to acknowledge the helpful suggestions provided by Don Emerson and Ron Jensen-Fisher of UMTA and by Don Pickrell of the Transportation Systems Center on an earlier version of this paper.

REFERENCES

1. S. L. Zimmerman. UMTA and Major Investments: Evaluation Process and Results. In *Transportation Research Record 1209*, TRB, National Research Council, Washington, D.C., 1989, pp. 32–36.
2. J. Hoover. Cost-Effectiveness of Rail Transit. Presented at the American Public Transportation Association Western Education and Training Conference, Seattle, Wash., 1990.
3. R. A. Johnston and M. A. DeLuchi. Evaluation Methods for Rail Transit Projects. *Transportation Research* Vol. 24A, No. 4, 1989. pp. 322–323.
4. *Procedures and Technical Methods for Transit Project Planning*. UMTA, U.S. Department of Transportation, Sept. 1986.
5. D. H. Pickrell. *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Costs*. UMTA, U.S. Department of Transportation, 1989.
6. M. Wohl and C Hendrickson. *Transportation Investment and Pricing Principles*. John Wiley and Sons, Inc., New York, N.Y. 1984, pp. 108–112.
7. UMTA. *Major Capital Investment Projects: Proposed Rulemaking*. 54 Fed. Reg. 17,891 (1989).
8. M. A. Bradley and H. F. Gunn. Stated Preference Analysis of Values of Travel Time in the Netherlands. In *Transportation Research Record 1258*, TRB, National Research Council, Washington, D.C., 1990, pp. 78–88.
9. *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements*. AASHTO, Washington, D.C., 1977.
10. C. H. Sharp. Time in Transport Investment. In *The Practice of Transport Investment Appraisal* (K. J. Button and A. D. Pearman, Eds.). Gower, Aldershot, England, 1983, pp. 181–195.
11. E. J. Mishan. *Cost-Benefit Analysis*. Unwin Hyman, London, England, 1988, pp. 305–310.
12. B. Pushkarev. *Urban Rail in America*. Indiana University Press, Bloomington, 1983, pp. 77–83.
13. V. R. Vuchic. *Urban Public Transportation: Systems and Technology*. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1981, pp. 83–86.
14. M. Pikarsky and D. Christensen. *Urban Transportation Policy and Management*. Lexington Books, Lexington, Mass., 1976, pp. 190–192.

The views expressed and analyses contained in this paper are solely those of the author.

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

PART 2

Transit Operations and Operations Planning

Transit Vehicle Meets System: A Method for Measuring Transfer Times Between Transit Routes

MARILYN M. REYNOLDS AND CHARLES D. HIXSON

One barrier to increased use of public transit is poorly scheduled transfer timing, especially between various types of transit or between various transit providers. It has been difficult to identify transfers that need improvement in a way that is convincing to transit providers. A computer system that calculates transfer utility and presents a detailed graphic display of arrivals and departures of the selected routes is described. This system can be used by metropolitan planning organizations and transit planners to show where transfers need to be improved between local bus routes and long-haul routes that are operated by a different provider. Data from San Francisco's Bay Area Rapid Transit and Alameda–Contra Costa Transit, the bus agency serving two of the region's counties, are used to illustrate the system's capability.

In a perfect world, all public transit would take us directly from our homes to where we wish to go, with no waiting. All people would use this remarkable service, and there would be no traffic congestion and much better air quality.

Instead, most transit service currently requires that we transfer, either from our car to a transit vehicle, or from one transit vehicle to another, to get to where we are going. Most plans for greater transit ridership and better transit service depend on users transferring from bus to bus, bus to rail, rail to rail, or rail to bus in greater numbers than ever before.

In the case of rapid rail and commuter rail, parking lots and structures are expensive to build and maintain. Most are full before the rush hour is half over. For these providers, new riders who come by bus and transfer can increase ridership with no additional parking facilities. In some areas, this may be the only way to obtain new riders.

In most urban areas, air quality is a growing concern. Because short auto trips (such as a daily drive to and from a train station) contribute disproportionate amounts of pollutants, one goal is to get people to leave their cars at home and take a bus to the station.

Bus systems are responding to the flight of jobs to the suburbs by changing from a pattern in which all transit lines converge on a central business district to a more gridlike structure of routes. Although it provides more service to more destinations, this system also requires more transfers.

If transferring can be made more pleasant, faster, and less problematic, more people will be willing to do it. Signage, public information, shelters, and schedule adherence all contribute to a better transfer experience. The most important factor, however, is the length of the scheduled wait. If the schedule is ill-planned, no amount of good operation will fix it. Therefore, the schedules are the basic foundation for good multioperator service.

Within a single transit provider's system, transfer times between routes are handled by the run cutting and scheduling (RUCUS) system. Standards for transfer times can be specified, and the resulting schedule reflects them. Where several transit operators' routes meet, schedule coordination becomes more difficult.

In the San Francisco Bay Area, for example, there are two long-haul rail systems: Bay Area Rapid Transit (BART) and Caltrain, and six large and many small bus–light-rail–ferry systems. Although most of the large operators have RUCUS systems, some do not, and there is no overall scheduling system. As the regional planning agency, the Metropolitan Transportation Commission (MTC) is charged with coordinating the schedules of these separate systems.

In practice, this involves mostly working toward better bus connections to and from the train stations. History and habit insist that the train schedules are not changed to meet buses, so all accommodation must be done by the bus systems. In this way, the situation is similar to many commuter rail–local bus combinations around the country.

Traditionally, MTC has looked at the train schedules and feeder bus schedules and noted where improvements needed to be made. This method is tedious and vulnerable to error, and there is no way to quantify improvement. Calculations have been done, but without visual illustration they were too abstract to prove a point to the bus operators who needed to improve their schedules at the rail stations.

This paper describes a computer system for measuring scheduled transfers between transit routes over several hours. To facilitate describing the way the system works, the term "meet" is used. In this context, a possible meet is any appearance of the feeder vehicle at the transfer point; a good meet is one that fits the wait criteria defined by the planner. The system can chart two or more schedules graphically and show whether each measured vehicle's appearance is in the user-defined "window of opportunity" for transfer or not. It can also calculate the number of possible meets, good meets, and the percentage of good meets. Such a calculation is based on assumptions that the planner using the system has already made: for each feeder line at a given transfer point, what is the least amount of time needed for transferring?, at which times is the feeder line feeding to the main line?, when is it receiving riders from the main line?

Metropolitan Transportation Commission, 101 Eighth Street, Oakland, Calif. 94607.

WHAT'S SO BAD ABOUT TRANSFERRING?

A new rider on any transit trip requiring a transfer has to find out how to do it: where to transfer, on which corner or bus stop or platform to wait, and so forth. When riders have to wait a long time, doubts and fears that the transfer won't work will arise. Transferring riders may have to stand on a windy platform or a rainy street corner or be exposed to what may be perceived as unpleasant street people, homeless people, panhandlers, and so forth. But any transit patron will agree that the most frustrating situation is watching the vehicle to which one wishes to transfer depart just as one arrives at the transfer point. This experience, and long waits in general, undoubtedly drive transit users back to automobiles. Seeing the train leave or the bus drive away every day—a common occurrence when meets are bad—could well give rise to disgruntlement with, lack of confidence in, and lessening taxpayer support of transit.

WHAT IS AN IDEAL TRANSFER SITUATION?

Anyone fortunate enough to have used the bus-ferry-bus combination from Victoria, British Columbia, to Vancouver probably remembers it as one seamless trip. The vehicles are dedicated to feeding passengers from one to the other, so there is a natural flow, with no waiting and no anxiety. In other cities, dedicated shuttles that meet commuter trains also provide this type of service.

Somewhat more hectic, but with almost as good a level of service, are timed transfer points at which all bus routes come to a location at the same time and dwell long enough for patrons to transfer between them. Unlike the one-to-one situation mentioned, the timed transfer point has a many-to-many transferring pattern. The large number of buses and the large size of bus bays means that some patrons must walk a distance to transfer, and the inevitable crossing of paths by hurrying riders contributes mild confusion to the scene. But the bottom line is that the transfers all occur within a short period, and riders get to where they are going. Figure 1 is a diagram of the bus boarding area at a BART station, where Alameda–Contra Costa (AC) Transit initiated a timed transfer point in 1988.

Another method of improving transfers is to hold up one vehicle until its "feeder" vehicle has arrived. This method is being used by means of a real-time computer system in Hamburg, Germany (*1*), and by means of a beacon in Contra Costa County, California, at BART stations on the Concord line, as well as at selected IND "A" subway stations in Queens, N.Y., and in other places. Such holds are normally used when the feeder vehicle is late or when schedules are especially tight.

OTHER TRANSFERS

When there are no dedicated transfers, timed transfers, or holds, the patron is less fortunate. Bus operators try to provide good transfers between their own feeders and long-haul lines; rail operators optimize transfers in the prevailing directions. But when a bus operator is required to have good meets with a train operation, such meets may be in direct competition with internal system transfers.

To make matters worse, the design of the rail system can introduce a note of schizophrenia to any attempt to provide bus meets. The BART system (Figure 2) has two inbound directions at all stations on the Richmond and Fremont lines during weekdays and one outbound direction (with twice as many trains) at the same stations. (On the Fremont line, alternating trains go to San Francisco and to Oakland/Berkeley/Richmond. On the Richmond line, trains go either to San Francisco or to Oakland/Hayward/Fremont.) These stations are served by AC Transit. Which trains should the buses meet?

In contrast, BART's Concord line, served by Central Contra Costa County Transit, has only one inbound direction, and the MARTA system in Atlanta (Figure 3) has two lines at right angles to each other, meaning only one inbound and one outbound direction at all stations except the transfer station, at which there are four outbound directions and no inbound ones.

MEASURING THE MEETS

On the surface, it would appear to be straightforward for planners to assess the transfer times between two routes. The

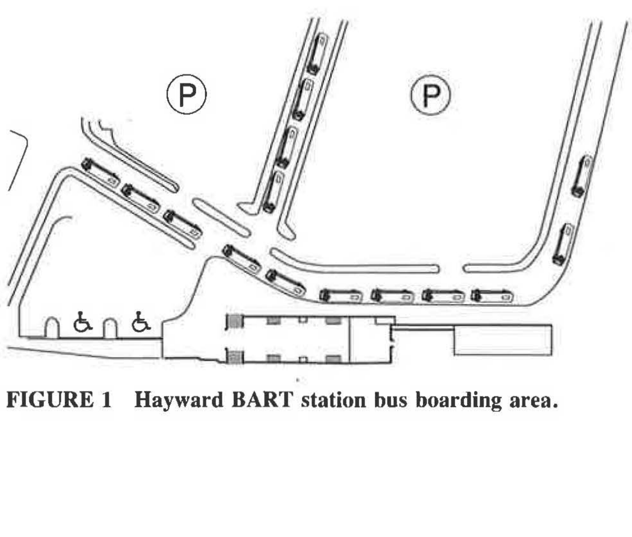


FIGURE 1 Hayward BART station bus boarding area.

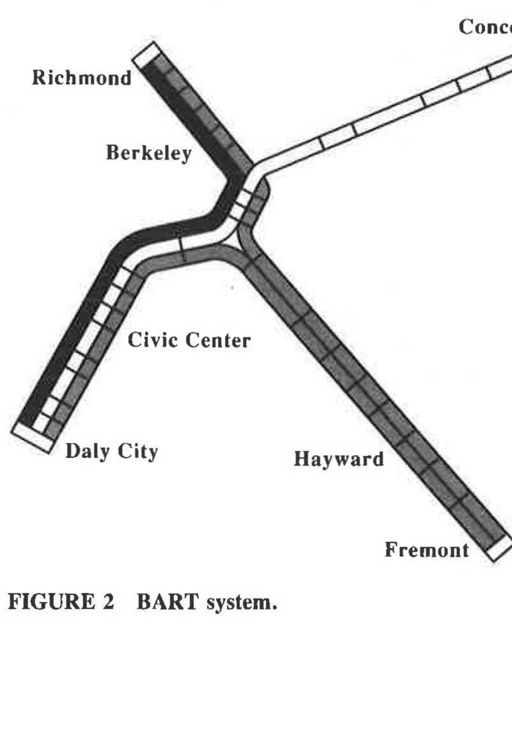


FIGURE 2 BART system.

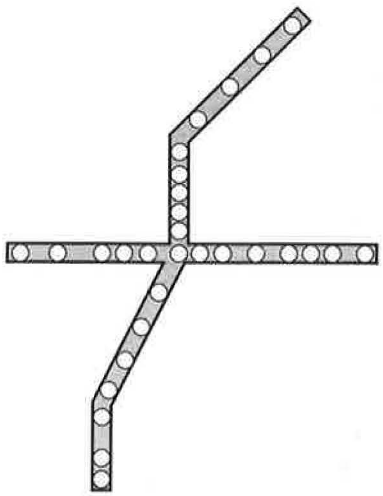


FIGURE 3 MARTA system.

only data needed are the schedules and the physical walking distances between the place where patrons get off the first vehicle and board the second. Table 1 shows a listing of two BART schedules at the Berkeley BART station and 2 bus schedules (out of 16). Although an analysis can be done with these data, such schedules are difficult to organize visually to promote an understanding of the analytical results.

Several studies have been done of bus-train meets in the Bay Area, including a 1988 study of interoperator schedule coordination that analyzed meets at 10 transfer point locations (*2*). Although much of this analysis was done by computer, a system to do this on a regular basis was not implemented.

One of the greatest barriers to setting up an automated system for display and analysis of transfer meets has been the difficulty of obtaining up-to-date transit schedules from more than one transit operator at a given transfer point on a routine basis. This barrier was removed at a few transfer points in the Bay Area by the implementation of an electronic schedule display system (ESDS), which shows departures of transit vehicles on video monitors (*3*). Figure 4 shows two screenfuls of data at the Berkeley BART station.

Keeping such systems running continuously required that software be developed to download data from AC Transit's RUCUS system and from BART's computer files of schedules. These ESDS data bases and their precursor data from the transit operators are therefore available for the sites at which systems are installed: currently at Berkeley BART, 12th Street BART, Hayward BART, and the Palo Alto Caltrain Station, and more will be installed in the next year.

File Edit 16:10:45

Scheduled Departures, 06–28–1991, at 4:10 PM

DESTINATION		1ST	NEXT	BOARD
BART				
	SAN FRANCISCO	4:23	4:38	Track Level
	FREMONT	4:17	4:33	Track Level
	RICHMOND	4:12	4:21	Track Level
AC TRANSIT				
7	ARLINGTON	4:19	4:34	Home Savings
7	CLAREMONT	4:19	4:34	J.C. Penney
8	GRIZZLY PEAK	4:30, LHS	4:50, LHS	Wells Fargo
9	WEST BERKELEY	4:15, (V)	4:30, (V)	Wells Fargo
15	OAKLAND	4:12	4:27	Wells Fargo
15	EL CERRITO	4:23	4:38	Great Western
40	EAST OAKLAND	4:17	4:29	Bank of America
43	EL CERRITO	4:13, SP	4:28	Home Savings

File Edit 16:11:20

Scheduled Departures, 06–28–1991, at 4:11 PM

DESTINATION		1ST	NEXT	BOARD
43	OAKLAND	4:12	4:27	J.C. Penney
51	MARINA	4:18, 3U	4:26, (M)	Home Savings
51	OAKLAND, ALAMEDA	4:16	4:24, (A)	J.C. Penney
64	OAKLAND	4:36	5:09	J.C. Penney
65	WEST BERKELEY	4:16	4:31	Home Savings
65	EL CERRITO	4:13	4:28	J.C. Penney
67	KENSINGTON	4:14	4:34	Great Western
F	SAN FRANCISCO	4:13	4:43	J.C. Penney
SHUTTLES				
	U.C. CAMPUS	4:20	4:30	Bank of America
	LBL (Restricted*)	4:20	4:30	Wells Fargo

FIGURE 4 Electronic schedule display system at Berkeley BART station.

TRANSIT MEETS SYSTEM

The Transit Meets System is very different than the ESDS: it is intended to be used by planners in their offices to give them the information necessary to improve schedules at trans-

TABLE 1 SELECTED SCHEDULES AT BERKELEY BART STATION, WEEKDAYS BETWEEN 6 a.m. AND 10 a.m.

BART SAN FRAN. (from Richmond)	BART FREMONT (from Richmond)	AC 7 ARLINGTON (NB, from Claremont)	AC 7 CLAREMONT (SB, from Arlington)
6:11	6:07	6:30	6:32
6:26	6:22	6:45	7:02
6:41	6:37	7:00	7:17
6:56	6:52	7:15	7:32
7:12	7:04	7:30	7:47
7:26	7:19	7:45	8:02
7:41	7:34	8:00	8:17
7:56	7:49	8:15	8:32
8:09	8:05	8:30	8:47
8:24	8:20	8:45	9:02
8:39	8:33	9:00	9:17
8:54	8:50	9:15	9:32
9:10	9:05	9:45	
9:25	9:20		
9:40	9:35		
9:55	9:50		

fer points, whereas the ESDS is used at a transfer point by the public to find when the next vehicle will depart. In addition, more schedule data are needed for the meets system. Both arrival and departure schedules are needed, because the meets must be measured in the direction of commute (inbound in the morning, and outbound in the evening).

Once a current data set of bus and train schedules at a given transfer point has been prepared and made available to the system, the transit meets may be examined. The system requests that the user make a number of choices and set several parameters. It operates on a Macintosh computer connected to a laser printer. This hardware was chosen because of the need for an understandable printed graphic display of the detailed information. The system is currently written as a custom program using Fourth Dimension, a proprietary data base package. A more portable version, written in C, is planned.

How It Works

1. A transfer point is chosen for analysis. This must be a place for which schedule data are available and of course where more than one route connects. In the first examples, the Berkeley BART station is selected as the transfer point.

2. One principle transit route must be selected, against which others are measured. All references to "route" mean both route and direction. In the first example, the BART train to San Francisco is chosen as the principal route. Because this example will look at buses feeding to BART, the "to BART" direction was chosen. Should it be BART feeding to buses, the "from BART" direction would be selected. This principal route need not be a train; a long-haul bus route may be used if bus-to-bus transfers are being studied.

3. One or more subordinate routes are selected, as well as the direction of feed. In the example, the AC Transit routes were chosen to be ones that feed riders to BART in the morning.

4. The time of day for analysis should be selected, as well as the type of service (weekday, Saturday, Sunday/holiday). Approximately 1 hr of detailed graphic display fits on a page. Even though this detail is voluminous, several hours should be chosen to have enough scheduled appearances of each route to be useful. The example looks at 7:00 a.m. to 9:30 a.m. on a weekday.

5. Finally, the transfer parameters are selected. What is the shortest reasonable time for this transfer (called "needed delay" by the system)? What is the longest time (called "allowable wait" by the system)? The minutes between needed delay and allowable wait make up the window of opportunity for a good transfer. For the example, needed delay is set at 2 min, allowable wait at 7 min. These times, of necessity, apply to all of the subordinate routes in the run; if some routes require a different transfer window, they should be removed from this run and set up in a separate run. The distance between the bus and rail stops will determine these parameters. Figure 5 is a diagram of bus boarding locations near Berkeley BART station.

Results of the Sample Run

Figure 6 is a full-sized page from the beginning of the detailed display. The page is divided into minutes, with the time printed at 5-min intervals. The second column shows the principal transit route, in this case the BART train to San Francisco. Its arrival/departure every 15 min causes a dark band to be printed across the page. For 2 min earlier, a slightly lighter band indicates the "not-enough-time" zone; in this run, 2 min was chosen by the user. Above that is the clear white window

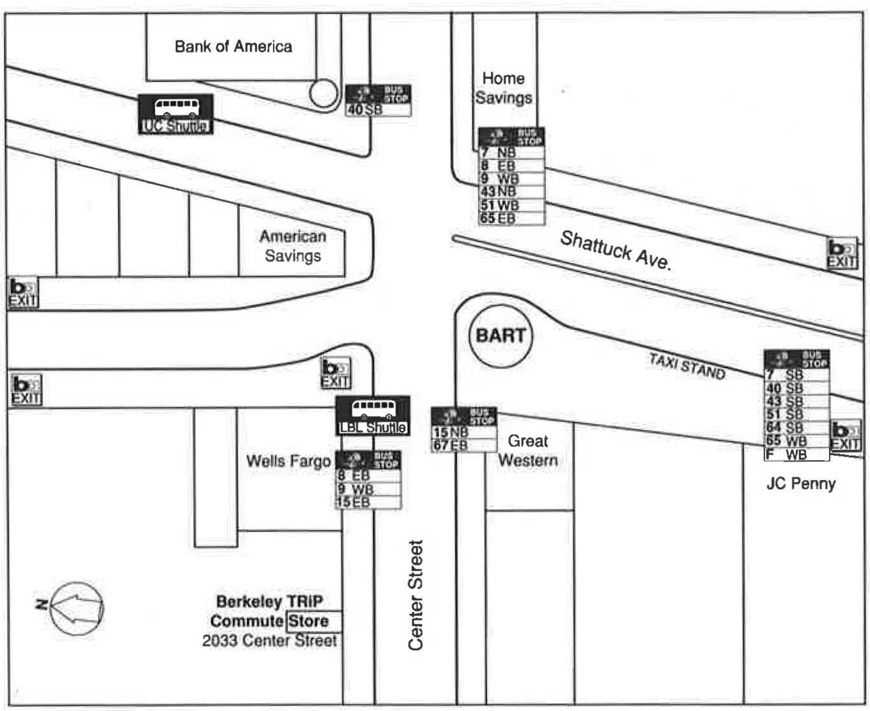


FIGURE 5 Bus boarding map, Berkeley BART station vicinity.

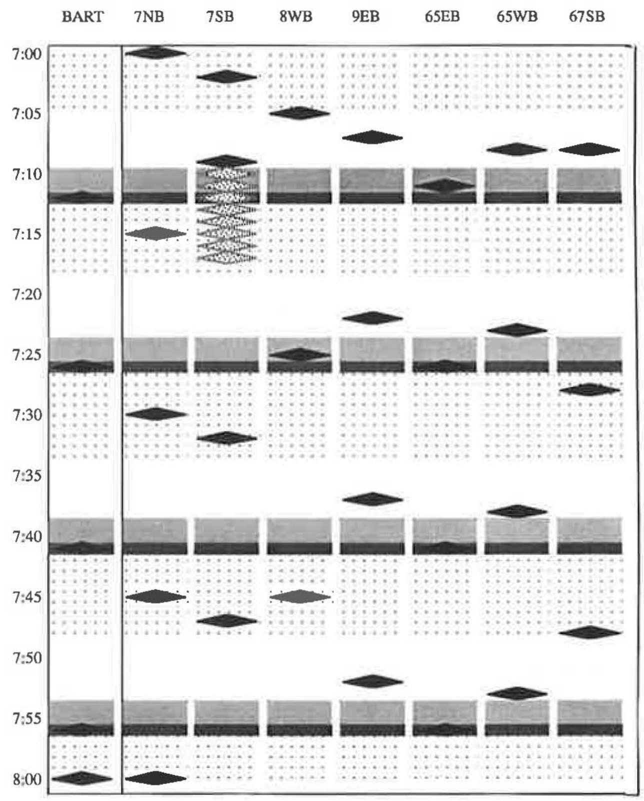


FIGURE 6 Example of detailed output: buses to BART.

of opportunity for a good transfer; and above that is the dotted area of "too long to wait," again, chosen by the user.

On this landscape, painted by the arrivals of the train, are printed the arrivals of each bus, one per column. It is visually apparent which one falls into each of the categories. Note that the arrival of the No. 75B is followed by a lighter version of the symbol for several minutes. This indicates a dwell time at the transfer point, which is not significant here because the transfer is from the bus to BART.

Figure 7 shows statistics of "goodness" of meets for the dependent routes during the entire run. Run counts include all appearances of the subordinate vehicle (totals) as well as those with too little time, too long a wait, and those that make a good meet. Percentages are calculated directly from these counts. "Average wait" is a measure of the average length of time a traveler would have to wait for the given transfer during the period. This value is calculated by using the actual number of minutes for all waits longer than the minimum; and for those under the minimum, using the time to the next vehicle, which is what happens in real life when a transferring patron just misses a bus or train.

BART	7NB	7SB	8WB	9EB	65EB	65WB	67SB
Not Enough Time			1 14.3%	4 40%	6 60%	4 44.4%	2 28.6%
Good Transit Meets		5 50%	3 42.9%	6 60%		5 55.6%	2 28.6%
Too long a Wait	10 100%	5 50%	3 42.9%		4 40%		3 42.9%
Total Runs	10	10	7	10	10	9	7
Minutes to Wait (mean)	10.1	7.5	9.2	8.8	13.7	8.5	10.4

FIGURE 7 Statistics: buses to BART (San Francisco).

Which Train Does the Bus Meet Well?

Arguments have arisen as to whether certain AC Transit bus routes have good meets with BART. One transit rider says the bus does not meet well; the other insists that the same bus line has good meets with BART. Could this discrepancy be because these buses meet one BART direction well and the other one poorly? To test this theory, a run identical to the first example was made, except that the principal route chosen was the Fremont BART train, which goes through Oakland. Figure 8 shows the statistics for this run. A person living on the No. 7NB line would find the bus-train connections to Fremont to be excellent; a neighbor who travels to San Francisco would not.

What Is the Evening Transfer Situation?

When commuters who use a bus-train combination have to work late or decide to stay in the city for dinner, how do they get home? Can commuters rely on a good transfer, or will they have a 40-min wait? The situation for these occasional late returns can determine whether a commuter will choose to drive to work on those days (or drive every day if the late returns are spontaneous). Figure 9 shows the same bus lines examined earlier, at the same station, for the period from 8 p.m. to 11:30 p.m. The BART schedule used is the combined runs to Richmond from San Francisco and Fremont; after 8:40 p.m. there are trains from Fremont only. Even though

BART	7NB	7SB	8WB	9EB	65EB	65WB	67SB
Not Enough Time		4 40%	2 28.6%				2 28.6%
Good Transit Meets	10 100%	5 50%	2 28.6%		1 10%		2 28.6%
Too long a Wait		1 10%	3 42.9%	10 100%	9 90%	9 100%	3 42.9%
Total Runs	10	10	7	10	10	9	7
Minutes to Wait (mean)	4.4	9.1	9.7	12.5	8.9	11.5	11.1

FIGURE 8 Statistics: buses to BART (Fremont).

BART	7NB	7SB	8WB	9EB	65EB	65WB	67SB
Not Enough Time		2 28.6%					
Good Transit Meets	5 71.4%	3 42.9%		4 66.7%	4 100%	4 100%	1 33.3%
Too long a Wait	2 28.6%	2 28.6%		2 33.3%			2 66.7%
Total Runs	7	7		6	4	4	3
Minutes to Wait (mean)	8.2	8.5		7.6	4.5	4.5	11.0

FIGURE 9 Statistics: buses from BART (evening).

the downtown Berkeley area is not a timed transfer location, certain buses have dwell times there during the evening. Such dwell times greatly increase the perception (and possibly the actuality) of security for patrons: to get out of a BART station and right onto the bus is far preferable to waiting 5 min on the street corner, even if the bus does not leave for 5 min.

Transfer possibilities range from excellent (the No. 65 in both directions) to poor (the No. 67). and nonexistent (the No. 8 does not run at all by then).

Although all runs of a given bus route (such as the No. 65) have good meets with the train, not all BART trains are met by the bus because of sparser schedules on the bus line. Patrons still must plan to take the trains that give them good meets with their buses. This program calculates the number of good meets from the number of possible meets (appearances of a vehicle on the subordinate route).

Are Bus-Train Transfers Better at Timed Transfer Points?

Does a transfer point with buses on a timed transfer schedule (including dwell time of 5 min) have better meets with BART? To examine this question, the Hayward BART station in Hayward, California, was chosen as the transfer point. In addition to timed transfers, this staion differs from the Berkeley station because many people transfer from BART to buses in the morning, with destinations in the industrial areas, as well as California State University, Hayward, and Chabot College. (In contrast, the University of California, Berkeley, is within walking distance of the BART station, and there is also a shuttle bus with 10-min headways.) Because of this situation in Hayward, three separate runs were made with each direction of BART train: residential area buses to BART, 7:00 a.m. to 9:30 a.m.; BART to industrial area buses, 6:00 a.m. to 8:00 a.m.; and BART to colleges, 7:30 a.m. to 9:30 a.m. Table 2 shows the percentages of good meets for these runs.

Hayward residents wishing to take a bus to San Francisco BART had better live on the No. 21 or on Kelly Hill (No. 95); otherwise, they are out of luck. If they wish to go to points in Oakland or north on BART, results are mixed and not particularly good from any line.

Perhaps workers arriving on BART fare better. In fact, those arriving from San Francisco who wish to take the No. 77 to points in South Hayward or to take the BART Express Bus U to Dublin are fortunate in their transfer, but no other bus patrons are. Travelers from Richmond, on the other hand, have a good transfer to the Samtrans 90E to San Mateo and a moderately good transfer to the industrial areas on the No. 86, or to San Leandro on the No. 81; the rest, not at all.

Finally, students on their way to Cal State or Chabot College have a 50 percent chance of having a good meet if they are coming from San Francisco, and no chance if they are coming on the train from Richmond. Overall, morning commute meets at Hayward BART seem to be somewhat worse than those at Berkeley BART.

It appears that, although timed-transfer schedules (of buses) work well for bus-to-bus transfers, they do not improve bus-to-train or train-to-bus transfers and may even make them worse.

CAUTION

Extreme care must be used in running the Transit Meets System, because the computer only performs the calculations and generates the graphic displays; choices and assumptions have been left to the user. The user must not only be sure that the schedules are correct and are named correctly so that they may be chosen properly, but also be knowledgeable about the physical layout of the transfer location and of the area served by the transit lines. For instance, to know the predominant direction of travel at various times of day requires knowledge of the location of residential and employment areas.

CONCLUSION

The Transit Meets System can be a useful tool for planners in measuring transfer utility for patrons. It can provide bench-

TABLE 2 PERCENTAGE OF GOOD MEETS AT HAYWARD BART

	BUS							
	AC21	AC80	AC90	AC91W	AC91E	AC94	AC95	BEXPU
RES AREAS TO SF BART	90%	0%	0%	0%	11%	0%	100%	0%
RES AREAS TO RICH BART	100%	17%	38%	20%	22%	40%	0%	33%

	AC77	AC81	AC85	AC86	SAMT90E	BEXPU
BART FR SF TO IND AREAS	100%	0%	0%	0%	0%	100%
BART FR RICH TO IND AREAS	0%	50%	0%	67%	100%	0%

	AC92E	AC92W
BART FR SF TO COLLEGES	50%	50%
BART FR RICH TO COLLEGES	0%	0%

marks in schedule coordination between two operators and a way to chart progress. The evening postcommute hours, in which long-haul vehicles feed riders to infrequent local bus routes, are rich areas for analysis because better evening transfer service will encourage more daily riders.

Before-and-after data from when a bus and rail transfer point are converted to timed bus transfers would be useful in planning future timed transfers, and individual operators could use the system to measure planned future schedules against existing ones.

REFERENCES

1. P. Burmeister and G. Sassmannshausen. Ensuring Rail and Bus Connections. *Railway Technology International*, 1989, pp. 145–147.
2. Crain & Associates. Interoperator Schedule Coordination Improvement Study Final Report. Metropolitan Transportation Commission, Oakland, Calif., 1988.
3. M. M. Reynolds. Electronic Schedule Display System. *Journal of Transportation Engineering*, July 1987, pp. 463–469.

Publication of this paper sponsored by Committee on Intermodal Transfer Facilities.

Queens-Manhattan Transit Improvements

HERBERT S. LEVINSON, JOSE M. ULERIO, AND ROBERT A. OLMSTED

Problems of peak-hour subway overcrowding continue to persist for Queens-Manhattan passengers in New York City. During the morning rush hour more than 110,000 passengers enter Manhattan via the 53rd Street, 60th Street, and 42nd Street tunnels. Ridership exceeds the capacity of each tunnel, resulting in serious passenger discomfort, especially on the Queens Boulevard E and F trains that use the 53rd Street tunnel. A fourth tunnel, the 63rd Street tunnel, is underused because it does not connect with the Queens subway and elevated lines. The long-range opportunities for improving subway service between Queens and Manhattan, including making better use of the 63rd Street tunnel, are evaluated using the physical feasibility, operating feasibility, ridership feasibility, capacities, costs, and institutional acceptability of more than 20 options. This analysis suggests a subway improvement strategy that involves completing the 63rd Street tunnel connection to the Queens Boulevard express and local tracks; connecting the 60th Street tunnel to the Flushing Line express track; using a rapid transit car capable of running on both tracks; possibly adding a fifth track through the Roosevelt Avenue station; and building a connection between the Queens Boulevard and Rockaway lines. Ultimately, the Long Island Rail Road main line should be connected with the lower level of the 63rd Street tunnel and an initial terminal provided on 3rd Avenue in Manhattan.

Queens, the largest of New York City's five boroughs in land area and the second-largest in population, has less subway service to Manhattan than the Bronx and Brooklyn. Rapid transit is limited to the 42nd (Steinway), 53rd, 60th, and 63rd Street tunnels. Four tracks (of which three are really effective) enter Manhattan from Queens, compared with six from the Bronx and nine from Brooklyn. The 1989 a.m. peak-hour riders entering Manhattan averaged 38,000 per track from Queens, compared with 25,000 crossing the 60th Street (Manhattan) cordon and 21,000 coming from Brooklyn.

The lack of subways across the East River and within Queens has caused serious overcrowding on the Queens Boulevard Line and the Flushing Line. Crowding on the Queens Boulevard E and F express trains is so severe that passengers are sometimes unable to board at the Roosevelt Avenue station. These problems of peak-hour subway overcrowding have persisted for many years.

Plans for alleviating this congestion have been proposed for several decades but relatively little action has been taken. The Metropolitan Transportation Authority (MTA) 1968 New Routes program called for Queens Boulevard express bypass tracks along the Long Island Rail Road (LIRR) between Forest Hills and Long Island City (the Queens Bypass); and a two-level, four-track 63rd Street tunnel with the upper level used by New York City Transit Authority (NYCTA) trains and the lower level by LIRR trains. The 63rd Street tunnel, with connections to the 6th and 7th Avenue subway lines in Manhattan, was completed and subway service was initiated to 21st Avenue, Queens, in 1989. However, because of the costs involved, the extensions into Queens were extensively restudied. This restudy led to the Northern Boulevard express-local connection proposal, which is currently under consideration.

H. S. Levinson and J. M. Ulerio, Polytechnic University, Six Metrotech Center, Brooklyn, N. Y. 11201. R. A. Olmsted, 33-04 91st Street, Jackson Heights, N.Y. 11372.

STUDY CONTEXT

UMTA (now the Federal Transit Administration), concerned with the costs and benefits of the proposed connection, authorized three universities in the New York metropolitan area to take a fresh and innovative look at the Queens-Manhattan public transportation improvement opportunities. One of these studies was conducted by the Transportation Training and Research Center of Polytechnic University, Brooklyn. The key findings of this study are presented.

TRAVEL DEMANDS

Approximately 115,000 subway passengers enter Manhattan from Queens during the morning rush hour of a typical weekday. Of these, about 48,000 ride the E and F trains through the 53rd Street tunnel, 35,000 ride the No. 7 (Flushing) trains through the 42nd Street tunnel, 30,000 ride the N and R trains through the 60th Street tunnel, and 2,000 ride the Q trains through the 63rd Street tunnel.

Projected employment growth in Manhattan and in Long Island City (Queens), coupled with population growth in outer Queens, is expected to result in a demand of 130,000 inbound peak-hour riders by 2000 [the corresponding value in the draft environmental impact statement (EIS) was 132,000 (*1*)]. By the year 2015, the number of a.m. peak-hour riders could approach 145,000. These ridership forecasts were used in developing and comparing 21 transit improvement options.

OPTION DEVELOPMENT

As stated previously, some 21 improvement options were analyzed. Seven options, Options 1-1 through 1-7, build upon the planned 63rd Street tunnel connection to the Queens Boulevard Line. Nine options, Options 2-1 through 2-9, include major extensions or adaptations of the Queens Boulevard Bypass, which was proposed in the past, and five options (Options 3-1 through 3-5) involve the LIRR.

The analysis assumed that the 63rd Street–Queens Boulevard local express connection (the Northern Boulevard Connection) would be built as planned. To defer this project, in search of an ideal solution would be counter–productive. The resulting delay (as in 1979) would set the project completion back another decade, during which period costs would escalate, and cost-effectiveness diminish. A brief description of each option follows.

Option 1-1: Queens Boulevard Local-Express Connection

This option, shown in Figure 1, is MTA's currently approved plan; funds for it are included in the Intermodal Surface Transportation Efficiency Act of 1991. The option provides a two-track connection between the east end of the 63rd Street Line and the existing local and express tracks of the Queens Boulevard Line. It also includes a four-track, two-level "bell-mouth" structure for possible future extensions of both the subway and LIRR (i.e. to a new subway yard or to a new route).

The Queens-Brooklyn crosstown G service is cut back at Court Square (at least during peak periods) to allow 14 additional inbound Queen's Boulevard trains into Manhattan via the 63rd Street tunnel. The cost, exclusive of rail vehicles, would be approximately $400 million to $450 million in 1990 dollars.

Option 1-2: Reverse Signaling

This option, suggested by NYCTA, calls for reverse signaling on Queens Boulevard express tracks between Queens Plaza and 71st Avenue. Reverse signaling during peak periods would make it possible to operate three tracks in the heaviest direction of travel, and operate only one track in the opposite direction. A new service yard would also be built at Sunnyside Yards to provide the necessary train storage.

Option 1-3: 63rd Street Connection to Queens (Brooklyn Crosstown Line)

This option connects the 63rd Street subway with both the Queens Boulevard and Queens-Brooklyn crosstown lines. It is designed to provide direct service between Manhattan and North Brooklyn and to increase the use of the 63rd Street tunnel.

Option 1-4: 60th Street Tunnel Connection to Flushing Line

This option provides additional track connections between the Astoria Line tracks at Queensboro Plaza and the Flushing Line west of 33rd Street to allow 60th Street tunnel trains to reach the express track without interfering with normal Flushing service to 42nd Street. The suggested track rearrangement, shown in Figure 2, creates a four-track section between Queensboro Plaza and 33rd Street. The Independent Rapid Transit (IRT) Flushing cars are 8 ft. 9 in. wide, and the Brooklyn–Manhattan Transit–Independent Line (BMT-IND) cars are 10 ft wide. Therefore, it would be necessary to use a car that can operate on both sets of tracks or possibly to provide gauntlet tracks. Additional storage would be provided east of the Main Street Flushing terminal.

Option 1-5: 60th Street Tunnel Connection to Relocated Flushing Line

This option connects the 60th Street–Astoria Line to a relocated Flushing Line across the Sunnyside Yards that eliminates the reverse curves through Long Island City. It includes a new Sunnyside station that is tied to the planned commercial development over the yards.

Option 1-6: Reversible Fifth Track at Roosevelt Avenue with Rockaway Branch Connection

This option constructs a fifth reversible track on the Queens Boulevard Line at Roosevelt Avenue to eliminate the bottleneck at this location. To realize the increase in capacity to the east, an express-local connection would be built at Rego Park to join the abandoned LIRR Rockaway Branch that would be reactivated for subway service. Some of the express service would use the fifth track to bypass Roosevelt Avenue.

Option 1-7: Revised Service Patterns at Roosevelt Avenue with Rockaway Branch Connection

This option provides an express-local connection to a reactivated LIRR Rockaway Line. However, instead of building a fifth track through Roosevelt Avenue, all peak-period, peak-direction express trains would skip this station, and thereby eliminate the expense of the fifth track.

Options 2-1, 2-2, and 2-3: Queens Bypass Options

The Queens Bypass options would connect the 63rd Street tunnel with the Queens Boulevard Line local tracks just east of the 71st and Continental Avenue station in Forest Hills. An intermediate station could be provided at Woodside. Option 2-1 proposes a single-track bypass for peak-period, peak-direction super-express service via 63rd Street with two tracks on each approach to the LIRR right-of-way. Option 2-2 provides a two-track bypass, for two-direction super-express service between 71st and Continental avenues and 21st Avenue. Option 2-3 is similar to Option 2-2, but it eliminates the station platform for the super-express service at 71st and Continental avenues.

Option 2-4: Queens Bypass Connection to Rockaway Line and JFK Airport

This option would connect the 63rd Street tunnel to the existing Rockaway Line via a double-track bypass along both sides (or the south side) of the LIRR and a reactivated LIRR Rockaway Branch. Super-express service would operate both

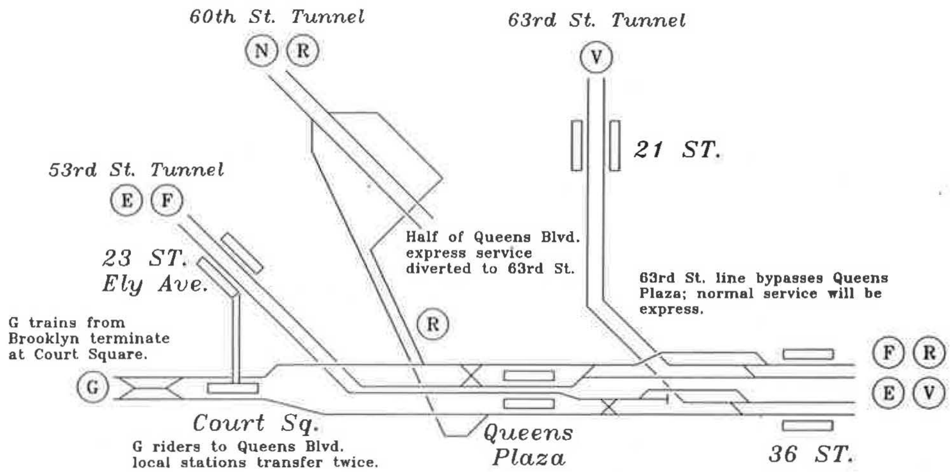


FIGURE 1 Planned local-express connection.

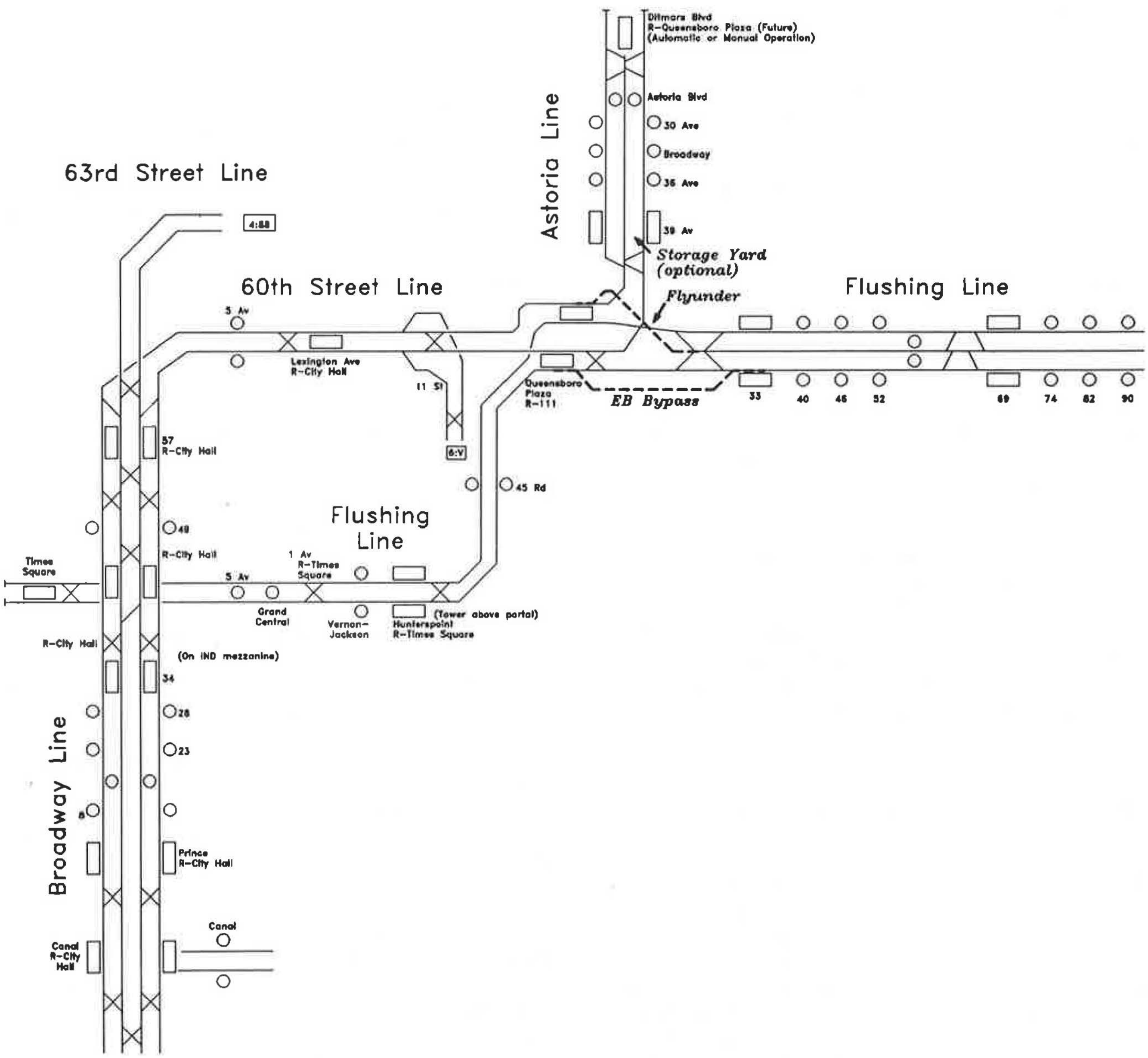


FIGURE 2 60th Street connection to Flushing express track.

ways during peak and base periods. A spur from the Aqueduct or Howard Beach area would connect with JFK International Airport. Alternatively, a people-mover could connect with the airport.

Option 2-5: Queens Bypass Connection with Southeast Queens Extension

This option develops the Queens Bypass from Long Island City to 71st and Continental avenues where it connects with the local tracks of the Queens Boulevard lines, extends the Archer Avenue (Queens Boulevard) Line via the LIRR Atlantic Branch to Laurelton, and reroutes the LIRR trains via the St. Albans Line. If the LIRR needs the Atlantic Branch's track capacity, the extension would require tracks parallel to the existing LIRR tracks.

Option 2-6: Queens Bypass Connection to East Central Queens Line

This option extends the 63rd Street Line to east Central Queens by way of a modified Queens Bypass along the north side of the LIRR tracks and a subway extension via the Long Island Expressway (LIE) to 164th Street.

Option 2-7: Bypass Truncated East of Grand Avenue

This option develops a two-track bypass along the north side of the LIRR that connects with the local tracks of the Queens Boulevard Line east of Grand Avenue. It provides faster service to the heavily used 67th Avenue, 63rd Drive, and Woodhaven Boulevard stations. Two variations of this option were also developed. One option provides a turnback for G trains east of Roosevelt Avenue to enable G trains to operate along part of Queens Boulevard; and a second option uses the existing tunnels of 63rd Drive to connect with a link to the Rockaways via the abandoned Rockaway Branch.

Option 2-8: LaGuardia Airport Extension via Northern Boulevard

This option extends the 63rd Street line along the north side of Sunnyside Yards (in subway) under Northern Boulevard, and then it is elevated via the Grand Central Parkway corridor to the Trump (New York–Washington–Boston) Shuttle and main terminals at LaGuardia Airport. It is designed to serve Northern Boulevard apartments in Jackson Heights, provide subway access to LaGuardia Field to Midtown, and relieve the Flushing Line.

Option 2-9: LaGuardia Airport Extension

This option provides a direct connection between the 63rd Street subway and LaGuardia Airport via an alignment that follows the north side of the Sunnyside Yards area (elevated), the National Railroad Passenger Corp. (Amtrak) Hell Gate-Bridge route (elevated), a high crossing of the Consolidated Rail Corp. (Conrail) Elevated Line (elevated), the east side of the Brooklyn-Queens Expressway (elevated) and descends to the airport service road system (mainly subway) to pass under the flight path.

Option 3-1: Long Island City–LIRR Transfer

This option provides an across-the-platform transfer station between the 63rd Street NYCTA subway line and the LIRR in Sunnyside Yards. Special low-fare LIRR turnback services would operate from this terminal to Rosedale and Queens Village in eastern Queens.

Option 3-2: 63rd Street Connection to Montauk Branch

This option connects the 63rd Street subway to the Montauk Branch of the LIRR with a second connection to the Jamaica (elevated) in the Lefferts Boulevard–Richmond Hill area. The Montauk Branch would be electrified and a block signal system would be provided for NYCTA operation. NYCTA trains would operate from Jamaica Center via the Montauk Branch and 63rd Street tunnel to Manhattan. LIRR freight service would be limited to late at night and passenger trains would be rerouted over the main line.

Option 3-3: 63rd Street Connection to Port Washington Branch

This option connects the 63rd Street tunnel to the Port Washington Branch of the LIRR (in addition to Queens Boulevard). The branch is converted to NYCTA operations, with local trains terminating at Little Neck and express trains continuing on to Port Washington. Single-track sections on the eastern end of the line would be double-tracked.

Option 3-4: Conversion of LIRR Main Line Tracks to NYCTA Operations

This option (a) connects the 63rd Street subway to the two former LIRR tracks between Woodside and Rego Park; (b) reroutes LIRR diesel trains via the Montauk Branch; (c) operates all LIRR service on the two center LIRR tracks from Woodside to Jamaica and operates NYCTA subway service via the two outer tracks (alternatively, to create joint NYCTA-LIRR running); (d) builds a flyover for NYCTA tracks through the Jamaica area; (e) connects NYCTA to the Atlantic Avenue Branch, which would be converted to NYCTA operation to Springfield Gardens; and (f) possibly reactivates the Rockaway Branch for subway service.

Option 3-5: LIRR Connection to Midtown Manhattan

This option calls for providing LIRR operations to midtown via the lower level of the 63rd Street tunnel. Alternatives include a connection to Grand Central Terminal, a terminal at Third Avenue and 49th Street, and a new cross-Manhattan line, which may extend to New Jersey and connect Amtrak's West Side line.

OPTION ASSESSMENT

Each option was assessed in terms of its physical feasibility, capital costs (excluding new rail cars), environmental effects, institutional implications, and cost effectiveness. Operating plans and ridership estimates were prepared for each option. The analysis procedure is shown in Figure 3.

Underlying Assumptions

The analysis reflects the following assumptions:

Ridership

The 130,000 a.m. peak-hour inbound subway riders anticipated by the year 2000 were allocated to the various Queens subway routes and the four Queens-Manhattan river crossings using the UMTA EIS (*1*) assignments as a base, making adjustments to reflect the number of trains operated on individual routes, the attractiveness of the service, and the characteristics of the areas served by the proposed extensions. Existing station boardings in proximate areas provided a further indication of ridership potentials of proposed new stations. The total inbound ridership was increased for several options to reflect the penetration of new market areas, and the expansion of subway capacity.

Capacity Requirements

The crush capacity (Level-of-Service F) represents the absolute maximum number of passengers that can be carried under conditions of extreme or intolerable overcrowding.

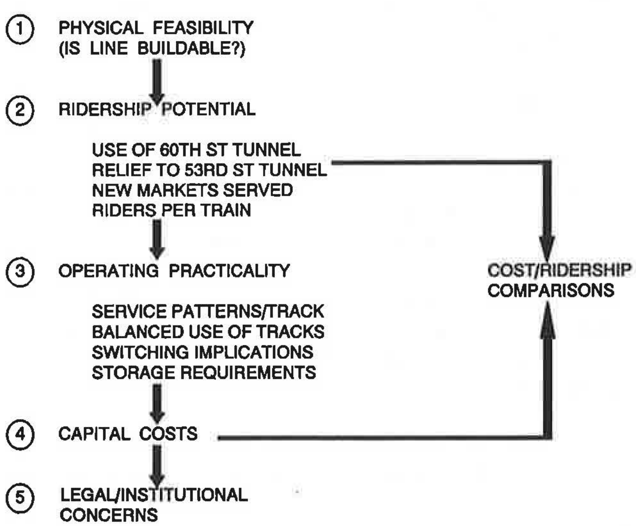


FIGURE 3 Analysis procedure.

However, for transport planning purposes consistent with past practices, schedule design capacities based on 3.0 ft^2/standing passenger (Level-of-Service E) were used. Accordingly, schedule-design capacities of 1,400 persons per BMT-IND train and 1,210 persons per IRT train were applied to the number of trains operating under each option across the East River. On the basis of 28 trains per track per hour, the following capacities were produced

Tunnel	*Passengers per hour*
63rd Street	39,200
60th Street	39,200
53rd Street	39,200
42nd Street (IRT)	33,880
Total	151,480

Thus, the four tunnels, if fully used, could comfortably accommodate the anticipated a.m. inbound riders well beyond the year 2010. In many options, however, only 14 to 21 trains per hour would be able to use the 63rd Street tunnel, resulting in total capacities of 131,880 to 141,680 riders. These capacities would comfortably accommodate riders until approximately the year 2005.

Operating Guidelines

The following service guidelines were used in developing and assessing options:

- Operating plans were developed for the inbound service to Manhattan during the a.m. peak hour. These plans, derived for comparative purposes, were based on the existing subway service pattern and the provision of not more than two basic services per trunk-line route.
- Subway service would operate at a minimum 2-min headway during the peak of the peak hour. For planning purposes, this translates into a maximum practical capacity of 28 trains per track per hour when peaking is taken into account. The 42nd, 53rd, and 60th Street tunnels would operate at their practical capacity of 28 trains per hour, whereas the number of trains using the 63rd Street tunnel would vary from 14 to 28 depending on the specific option.
- The E and F Queens Boulevard express services would operate via the 53rd Street tunnel. These specific impacts were only assessed for the planned Queens Boulevard connection although it could apply to many options.
- The added service in Queens through the 63rd Street tunnel would be linked with the existing services that terminate at 21st Avenue. However, in some options an additional service might operate via 63rd Street. In all cases, the effects on existing Sixth and Broadway–Seventh Avenue services were considered and included possible turnback of trains in lower Manhattan.
- Because of track limitations, some changes in Queens-Brooklyn service linkages may be required.
- The crosstown Queens-Brooklyn G service is cut back at Court Square during peak hours in many of the options and in some cases, further refinements of operation plans might allow this service to continue to Queens Plaza or to 71st and Continental avenues. However, better use is made of the Queens Boulevard local tracks when the G service is cut back.

• Improvements at the Harold Interlocking and the new West Side storage yard should allow the number of peak-hour trains on the LIRR to be increased and Jamaica would become the new limitation.

Costs

Order-of-magnitude capital costs were derived from a variety of sources and adjusted to 1990 levels. The estimates for the bypass and bypass-related options were drawn from a July 1981 Queens transit alternatives study. The costs for the Northern Boulevard connection were based on those contained in the May 1990 draft EIS (*1*) and other costs were based on the following unit values and were subject to engineering judgment when complex construction would be required:

	Cost per 2-track mile (millions of dollars)
Subway	250–350
Elevated structure	75
New elevated embankment only	50
Existing embankment or grade	25

Rail car costs were not estimated because they depend in part on the amount of interlining possible and detailed schedule development.

Ridership Comparisons

Anticipated year 2000 a.m. peak-hour ridership forecasts for each option are presented in Tables 1 and 2. Table 1 compares ridership by option and river crossing and gives the estimated total inbound peak-hour capacity. Table 2 gives the trains using the 63rd Street tunnel by option and identifies the number and sources of new riders, giving expected relief on each river crossing.

Findings presented in Tables 1 and 2 are outlined as follows:

1. Trains through the 63rd Street tunnel—The number of trains entering Manhattan through the 63rd Street tunnel in the a.m. peak hour ranges from 14 (Option 1-1: planned Queens Boulevard Connection) to 28 (Option 3-3: Port Washington Connection). Most options have 21 trains going through the tunnel.
2. Passenger Capacity—The total peak-hour inbound capacity across the East River ranges from about 132,000 (Option 1-1: Queens Boulevard Connection and Option 2-7: Queens Boulevard Connection east of Grand Avenue) to 151,000 (Option 3-3 *b*: 63rd Street-Port Washington Connection). The Queens Bypass (Option 2-2) currently has a capacity of 142,000, but this could easily be increased to 151,000. Most of the other options have a total capacity of 142,000. The year 2000 base demand is 130,000 and the year 2010 base demand is 145,000.
3. Total Riders—The anticipated number of inbound riders for the 2000 a.m. peak hour reflects the attractiveness of the subway service and its ability to serve new markets. Ridership ranges from 130,000 to 140,000 people. The largest number of riders (140,000) is expected on the Queens Bypass–Springfield Gardens Extension (Option 2-5) and on the Port Washington NYCTA operation (Option 2-6).

The Queens Bypass with an LIE extension (Option 2-6) has 137,000 riders, and the Queens Bypass–Rockaway–JFK Line (Option 2-5) and the Northern Boulevard–LaGuardia Line (Option 2-9) have 135,000 riders each.

TABLE 1 SUMMARY OF RIDERSHIP FORECASTS—EAST RIVER CROSSING (YEAR 2000: INBOUND A.M. PEAK HOUR)

OPTION	DESCRIPTION	Trains Using 63rd Street Tunnel	CAPACITY	TUNNEL					G SERVICE QUEENS TERMINAL
				63rd	60th	53rd	42nd	TOTAL	
0	No Build	14	131,880	3,000	36,000	53,000	38,000	130,000	71st
1-1 (a)	63rd St exp-local conn. (exp via 53rd)	14	131,880	16,000	34,000	44,000	36,000	130,000	Court Square
1-1 (b)	63rd St exp-local conn. (exp via 53rd, 63rd)	28	131,880	21,000	30,000	43,000	36,000	130,000	Court Square
1-2	63rd St conn. / reverse signaling	21	141,680	25,000	33,000	40,000	36,000	134,000	71st
1-3	63rd St conn. to Queens Blvd & crosstown line	21	141,680	21,000	34,000	42,000	35,000	132,000	Court Square
1-4	63rd St conn.; 60th conn. to Flushing line express track	21	141,680	24,000	35,000	42,000	31,000	132,000	Manhattan
1-5	63rd St conn.; 60th St conn. to Flushing line; Flushing line relocated across Sunnyside Yards	21	141,680	24,000	35,000	42,000	31,000	132,000	Court Square
1-6	63rd St conn., reversible 5th track at Roosevelt Ave; ext. to Rockaways	21	141,680	23,000	33,000	41,000	36,000	133,000	Court Square
1-7	63rd St conn.; revised service pattern at Roosevelt Ave.; ext. to Rockaways	21	141,680	22,000	35,000	40,000	36,000	133,000	Court Square
2 - 1,2,3	Queens Bypass	21	141,680	27,000	31,000	40,000	36,000	131,000	71st
2-4	Queens Bypass to Rockaway conn.	21	141,680	19,000	34,000	46,000	36,000	135,000	71st
2-5	Queens Bypass-Springfield Gardens ext.	21	141,680	28,000	34,000	42,000	36,000	140,000	71st
2-6	Queens Bypass to LIE ext.	21	141,680	27,000	33,000	42,000	34,000	136,000	71st
2-7 (1)	Queens Blvd conn. east of Grand Ave	14	131,880	19,000	33,000	42,000	36,000	130,000	Court Square
2-7 (2)	Queens Blvd conn. east of Grand Ave with ext. to Rockaways	14	131,880	19,000	34,000	44,000	36,000	133,000	Roosevelt Ave
2-8 (a)	LaGuardia ext. via Northern Blvd	21	131,880	20,000	34,000	46,000	35,000	135,000	71st
2-8 (b)	LaGuardia ext. via Northern Blvd	21	141,680	24,000	34,000	42,000	35,000	135,000	Court Square
2-9	LaGuardia ext. via BQE	21	141,680	19,000	34,000	44,000	36,000	133,000	Court Square
3-2 (a)	63rd St - Montauk Branch conn.	21	141,680	19,000	34,000	36,000	36,000	135,000	71st
3-2 (b)	63rd St - Montauk Branch conn.	21	141,680	24,000	33,000	42,000	36,000	135,000	Court Square
3-3 (a)	63rd St - Port Washington conn.	21	141,680	27,000	34,000	46,000	33,000	140,000	71st
3-3 (b)	63rd St - Port Washington conn.	28	151,480	33,00	34,000	40,000	33,000	140,000	Court Square

TABLE 2 COMPARATIVE ANALYSIS OF RIDERSHIP IMPACTS (YEAR 2000: INBOUND A.M. PEAK HOUR)

OPTION NUMBER	TRAINS USING 63rd ST TUNNEL	QUEENS TERMINAL FOR G SERVICE	ADDITIONAL SUBWAY RIDERS ACROSS EAST RIVER CORDON				RELIEF AFFORDED (Difference from No Build)		
			Total	From Bklyn subway lines	From LIRR	New	60th	53rd	42nd
1-1 (a)	14	Court Sq	---				2000	9,000	2000
1-1 (b)	14	Court Sq	---				6000	10,000	2000
1-2	21	71st	4000	4000 d	a	a	3000	13,000	2000
1-3	21	Manhattan	2000	1200	800		2000	11,000	3000
1-4	21	Court Sq	2000		800	1200	1000	11,000	7000
1-5	21	Court Sq	2000	a	a	a	1000	11,000	1000
1-6	21	Court Sq	3000	1500	700	800	3000	12,000	2000
1-7	21	Court Sq	3000	1500	700	800	1000	13,000	2000
2-1	21	71st	4000	a	a	a	5000	13000	2000
2-2	21	71st	4000	a	a	a	5000	13000	2000
2-3	21	71st	4000	a	a	a	5000	13000	2000
2-4	21	71st	5000	1500	700	2800	2000	7000	2000
2-5	21	71st	10000	4000 d	2000	4000	2000	11000	2000
2-6	21	71st	7000	---	---	7000	3000	11000	4000
2-7 (a)	14	Court Sq	---	---	---	---	3000	11000	2000
2-7 (b)		Roosevelt Ave	3000	1500	700	800	3000	9000	2000
2-8 (a)	14	71st	5000	---	---	5000	2000	7000	3000
2-8 (b)		Court Sq	5000	---	---	5000	2000	11000	3000
2-9	14	Court Sq	3000	---	---	3000	2000	9000	2000
3-1 b			---	---	---	---	2000	9000	2000
3-2 (a)	21	71st	5000	500	2000	2500	2000	7000	2000
3-2 (b)	21	Court Sq	5000	500	2000	2500	3000	7000	2000
3-3 (a)	21	71st	10000	---	8000	2000	2000	10000	5000
3-3 (b)	28	Court Sq	10000	---	8000	2000	2000	10000	3000

Notes: (a) Not specified.
(b) Assumed, no ridership forecasts.
(c) No ridership forecasts for options 3-4 or 3-5.
(d) Time shift from existing services.

4. Use of 63rd Street Tunnel—The number of inbound peak-hour passengers through the 63rd Street tunnel ranges from 16,000 (Option 1) to 33,000 (Option 3-3*b*). The Queens Bypass with the Southeast Queens Connection (Option 2-5) results in 28,000 riders, and the Queens Bypass and Queens Bypass–LIE extensions (Options 2-2 and 2-6) result in 27,000 riders.

5. Relief Afforded—The relief afforded to the 53rd Street tunnel ranges from 9,000 to 13,000 riders. The greatest relief occurs when additional express services are operated to 179th Street (as in the case of the Queens Bypass options), or when 14 local trains, in conjunction with other service improvements, are operated from 179th Street via the 63rd Street tunnel. Options that relieve the tunnel by 13,000 trips include reverse running (Option 1-2) and the Queens Bypass (Option 2-2).

—The relief afforded to the 42nd Street tunnel ranges from 2,000 to 7,000 passengers. The greatest relief—5,000 and 7,000 passengers, respectively—results from the Port Washington Extension (Option 3-3) and the 60th Street connection to the Flushing express track (Options 1-4 and 1-5). Several options attract passengers from the LIRR, and thereby relieve the railroad. The greatest relief (8,000 passengers) results from the Port Washington Connection (Option 3-3).

—The Montauk-Archer NYCTA operation (Option 3-2) and the Bypass–Southeast Queens Extension (Option 2-5) each attract 2,000 LIRR peak-hour riders.

6. Queens-Brooklyn G Operation—Options that incorporate the Queens Boulevard Connection require the G service to be turned back during peak hours at Court Square (The exception, perhaps, is the reverse running, which might allow inbound G service.) The Queens Bypass options enable the G service to begin at 71st Avenue. However, the extension to Rockaways (Option 2-4) provides more relief to the Queens Boulevard Line if the number of trains on Queens Boulevard is increased and the number of trains from the Rockaways is decreased. The Flushing corridor (Options 2-8, 2-9, and 3-2) and the Montauk (Option 3-2) also require the G Line to be cut back at Court Square to allow more trains on Queens Boulevard. The two options that provide service to the 60th Street tunnel from Flushing (Options 1-4 and 1-5) reduce the number of R trains entering Queens Plaza from 14 to 7. These R trains are shifted to the 63rd Street tunnel which makes it possible for the G trains to operate from the eastbound Queens Plaza track. Running more R trains via the 63rd Street tunnel in some of the other options might also allow this service modification. The point remains, however, that to maximize Manhattan-bound capacity, it is best to modify the G operation in many options.

Costs

Estimated construction costs in 1990 dollars for the various options are presented in Table 3, and the key findings are as follows:

1. The Northern Boulevard option (Option 1-1) would cost about $450 million.

TABLE 3 COST SUMMARY OF QUEENS TRANSIT OPTIONS (IN MILLIONS OF 1990 DOLLARS)

NUMBER	OPTION	Est. Incremental Cost of Option	Est. Cost Northern Blvd Option	TOTAL
1-1	63rd St Local/Express Connection (Northern Boulevard Connection - NBC)		$ 450	$ 450
1-2	3:1 Reverse Signaling - reverse signaling - yard, including connections TOTAL	 $ 50 700 750	450	200
1-3	63rd Street GG Connection	250	450	700
1-4	60th St-IRT Joint Running - structural changes at Queensboro Plaza - storage (east of Main Street) - gap problem solution TOTAL	 75 100 25 200	450	650
1-5	60th St-IRT Joint Running - structural changes at Queensboro Plaza - storage (east of Main Street) - gap problem solution - Flushing line relocation TOTAL	 25 100 25 125 275	450	725
1-6	Reversible Fifth Track at Roosevelt Avenue with Rockaway Connection - fifth track (same level) - connection to Rockaway at 63rd Dr (local/express) - Rockaway extension to Liberty Avenue TOTAL	 150 200 150 500	450	950
1-7	Revised service pattern at Roosevelt with Rockaway connection - connection to Rockaway Branch at 63rd Drive - Rockaway ext to Liberty Avenue TOTAL	 200 150 350	450	800
2-1	Single-track bypass ($660 in 1984 without cars)	$ 850	$ 450	$ 1300
2-2	Double-track bypass	900	450	1350
2-3	Double-track bypass without 71st Avenue	850	450	1300
2-4	Bypass (west half) with connection to Rockaway Line and JFK spur - bypass (west half) - Rockaway branch to Liberty Avenue - JFK extension TOTAL	 425 175 300 900	450	1350
2-5	Bypass plus Archer Avenue S.E. Queens extension - bypass - S.E. Queens extension on LIRR tracks TOTAL	 900 200 1100	450	1550
2-6	Bypass (west half) with connection to East Central Queens Line via L.I.E. - bypass (west half) - L.I.E. subway extension including terminal facilities TOTAL	 400 1100 1500	450	1950
2-7	Truncated Bypass - bypass to Grand Street - GG turnback east of Roosevelt Avenue Subtotal - Rockaway branch to Liberty Avenue TOTAL	 $ 600 100 700 200 900	 $ 0 0	 $ 700 900
2-8	LaGuardia Airport extension via Northern Boulevard - if from bellmouth - if from 54th Street (1.5 miles shorter)	 1200 800	 450 450	 1650 1250
2-9	LaGuardia Airport extension (Brooklyn-Queens Expressway) - if from bellmouth - underground - if from bellmouth - part elevated	 1300 750		
3-1	LIRR - Long Island City Transfer (Montauk transfer plan) ($291 in 1984 without cars)	$ 400	$ 450	$ 850
3-2	63rd Street connection to Montauk Branch (Montauk/Archer Avenue plan) ($381 in 1984 without cars)	550	450	1000
3-3	63rd Street connection to Port Washington branch - 63rd Street connection to Port Washington tracks - conversion of Port Washington Line to NYCTA operation TOTAL	 250 270 520	450	970
3-4	Conversion of LIRR Main Line tracks to NYCTA operation	*OPTION DROPPED*		
3-5	LIRR 63rd Street line to Grand Central Terminal - Queens connections (2 tracks* only) plus one of the following 1. Grand Central link, or 2. 3rd Avenue terminal** 3. crosstown (2 tracks) on 50th Street (to 10th Avenue) ***	 600 750 600 1100	 450	 1050 750 600 1100

NOTES:
* Queens Connection - Two track connection to LIRR instead of formerly proposed four track connection.
** 3rd Avenue Terminal, 4 track, single level, no tail tracks for storage.
*** A future second crosstown tunnel for added capacity would add another $500 million.

2. Options 1-2 through 1-7, which build on this option, would cost from $200 million to $500 million more.

3. The original Queens Bypass option (Option 2-2) would cost $900 million. Thus, if it were built in lieu of the planned Northern Boulevard connection, it would cost about $900 million today. However, building it in addition to the Queens–Northern Boulevard connection would cost $1.3 billion overall. A truncated bypass (Option 2-7) with a connection to the Rockaway Branch would cost $900 million. All other bypass-related options, taken with the Northern Boulevard connection, would exceed $1 billion.

4. Conversion of the Port Washington Branch to NYCTA operation would cost about $520 million about the costs for the Queens–Northern Boulevard connection.

5. Extension of the LIRR into Manhattan via the lower level of the 63rd Street connection would cost more than $1 billion plus the $450 million cost for the Northern Boulevard connection.

Cost Effectiveness

The cost effectiveness of each option was estimated by a simplified incremental cost analysis that compared the incremental benefits achieved over Option 1-1 with the incremental capital costs. The benefits assumed inbound a.m. peak-hour use of the 63rd Street tunnel and inbound a.m. trip reductions in the 53rd Street tunnel. The results of this analysis are presented in Table 4.

- The cost-effective options, in terms of using the 63rd Street tunnel, in order of effectiveness are Option 1-4 (60th Street trains using Flushing Express track); Option 3-3*b* (63rd Street tunnel connected to Port Washington Branch); Option 1-5 (60th Street trains using Flushing Express track with Flushing Line relocated); and Options 2-1 and 2-3 (Queens Bypass assuming that the Northern Boulevard connection is not built).
- The cost-effective options in terms of affording relief to the 53rd Street tunnel are Option 2-7*a* (63rd Street extension to Grand Avenue in lieu of the Northern Boulevard connection); Option 1-7 (Northern Boulevard connection with express trains skipping Roosevelt Avenue); 60th Street tunnel service via the Flushing express track; and Options 2-1 and 2-3 (the Queens Bypass without the Northern Boulevard connection).

It is evident that the Queens Bypass, if it is built in place of the Northern Boulevard connection, fares well in this analysis on both accounts. With the Northern Boulevard connection, the 60th Street link to the Flushing express track and the conversion of the Port Washington Line to NYCTA operation also appear to be cost-effective.

Table 5 presents a summary assessment of the various options. On the basis of this assessment, in conjunction with the cost-effectiveness analysis, the following options were screened from further consideration:

- Option 1-2 (high costs, adverse impact in off-peak direction),
- Option 1-3 (difficult construction, low ridership),
- Option 2-1 (difficult operations, limited flexibility),
- Option 2-4 (poor cost effectiveness),
- Option 2-6 (high costs because of difficult subway construction),
- Option 2-7 (not practical once the Northern Boulevard connection is built),
- Options 2-8 and 2-9 (high cost because of subway construction, little relief, poor cost effectiveness),
- Option 3-1 (high cost and little relief, nullified by 63rd Street–Queens Boulevard connection),
- Option 3-2 (community concerns, little additional relief over Queens Boulevard connection), and
- Option 3-4 (not operable in Jamaica).

TABLE 4 COST EFFECTIVENESS OF OPTIONS OVER OPTION 1-1*a* (IN MILLIONS OF DOLLARS PER THOUSAND DAILY RIDERS FOR INBOUND A.M. PEAK HOUR)

OPTION	63rd Street Tunnel			Reduction in 53rd Street Tunnel		
1-1	Base	Option	Rank	Base	Option	Rank
1-2	83.3			187.5		9
1-3	50.0		8	125.0		5
1-4	25.0		1	100.0		3
1-5	34.4		3	136.0		7
1-6	71.4			166.7		8
1-7	58.3		10	87.5		2
2-1	77.3	(36.4)	4	212.5	(100)	3
2-2	81.8	(40.9)	6	225	(112.5)	
2-3	77.3	(36.4)	4	212.5	(100)	3
2-4	30.0			NEGATIVE		
2-5	91.7	(54.1)		550	(325)	
2-6	136			750		
2-7a	50		8	75		1
2-7abc	150			NEGATIVE		
2-8a	375	(300)		NEGATIVE		
2-8b		(100)		400		
2-9	250			NEGATIVE		
3-2a	183.3			275		10
3-2b	68.7			275		10
3-3a	47.3		7	NEGATIVE		
3-3b	30.6		2	130		6

NOTE: Values in parentheses assume Northern Boulevard connection is not built.

Emergent Directions

The analyses reaffirm the desirability of building the Queens Bypass. The bypass provides effective relief to the Queens Boulevard corridor, achieves good use of the 63rd Street tunnel, enables the Queens-Brooklyn service to continue operating to and from 71st Avenue, and makes it possible to extend services to eastern and southeastern Queens as demand arises

TABLE 5 SUMMARY OF ASSESSMENT OF QUEENS-MANHATTAN TRANSIT OPERATIONS

OPTION	Capital Cost (Millions of 1990 dollars)	Queens Terminal for G Service	Trains Using 63rd St Tunnel	Passengers Using 63rd St Tunnel	Relief to 53rd St Tunnel	New Subway Trips Across East River	Coverage of New Areas	Engineering Implications	Development Impacts	Institutional Consideration	Remarks
1-1 (a)	450	Court Sq	14	16,000	9,000	-----					
1-1 (b)	450	Court Sq	14	21,000	10,000	-----					
1-2	1200	71st Ave	21	25,000	13,000	4,000					Adverse operation in off-peak direction
1-3	700	Manhattan	21	21,000	11,000	2,000	Direct service North Brooklyn - Manhattan	Very difficult construction	North Brooklyn		Not practical
1-4	650	Court Sq	21	24,000	11,000	2,000		Requires special care			
1-5	725	Court Sq	21	24,000	11,000	2,000			Sunnyside Yard		Eliminates Queensboro Plaza transfer
1-6	950	Court Sq	21	23,000	12,000	3,000	Direct service - Rockaways	Disrupts service during construction			
1-7	800	Court Sq	21	22,000	13,000	3,000					
2-1	1300	71st Ave	21	27,000	13,000	4,000					Operationally not practical
2-2	1350 [1]	71st Ave	21	27,000	13,000	4,000					
2-3	1300	71st Ave	21	27,000	13,000	4,000					
2-4	1350	71st Ave	21	19,000	7,000	4,000	Direct service - JFK/Rockaways				
2-5	1550	71st Ave	21	28,000	11,000	10,000	Southeast Queens				
2-6	1950	71st Ave	21	27,000	11,000	7,000	Eastern Queens				
2-7 (a)	600 [2]	Court Sq	14	19,000	11,000	-----					
2-7 (a,b,c)	900	Grand Ave	14	19,000	9,000	3,000	Direct service - Rockaways				
2-8 (a)	1650	71st Ave	14	20,000	7,000	4,000	Jackson Heights-LaGuardia				
2-8 (b)	1250	Court Sq	21	24,000	11,000	5,000					
2-9	1200	Court Sq	21	19,000	9,000	3,000	LaGuardia				
3-1	850	Court Sq	14	(4)	(4)	(4)				Yes	Poor passenger attraction
3-2 (a)	1000	71st Ave	21	19,000	7,000	5,000	Richmond Hill, Glendale, Maspeth			Community objects to plan	Impacts LIRR freight service
3-2 (b)	1000	Court Sq	21	24,000	11,000	5,000					
3-3 (a)	970	71st Ave	21	27,000	7,000	10,000	Bayside/ Great Neck			Yes	Allows 7 more peak hour trains into Penn Station
3-3 (b)	970	Court Sq	28	33,000	13,000	10,000				Yes	
3-4	-----	Court Sq	14	(4)	(4)	(4)	Requires major construction in Jamaica			Possibly	Not practical - limits LIRR capacity at Jamaica
3-5	1650 [3]	Court Sq	14	(4)	(4)	(4)	Very costly construction		Midtown	May allow benefit-assessment financing	Very long range

Notes:
[1] 900 without Northern Boulevard connection.
[2] Without Northern Boulevard connection.
[3] To 3rd Avenue terminal, to Grand Central Terminal.
(4) Not estimated.

and resources permit. However, to build both the bypass and the Northern Boulevard connection would result in redundant investments. The complete bypass makes sense *only* if the planned Northern Boulevard connection is not built. Developing the bypass at this time would add delays, costs, and community acceptance problems. The Northern Boulevard express-local connection (Option 1-1) should be completed as soon as possible. Other viable options include connecting the 60th Street tunnel to the express tracks of the Flushing Line (Option 1-4), followed by possibly adding a fifth track through the Roosevelt Avenue station and building a connection between the Queens Boulevard and Rockaway lines (Option 1-6).

Two viable LIRR options emerge from this analysis: (a) the Port Washington Branch could be converted to NYCTA operation and routed through the existing 63rd Street tunnel (Option 3-3), representing an alternative to Options 1-4 and 1-7, and (b) ultimately, the LIRR should enter midtown through the lower level of the 63rd Street tunnel (Option 3-5).

TRANSIT IMPROVEMENT PROGRAM

The recommended transit improvement program builds on the comparative analysis. This program, shown in Figure 4, is keyed to the transport needs of the Queens-Manhattan

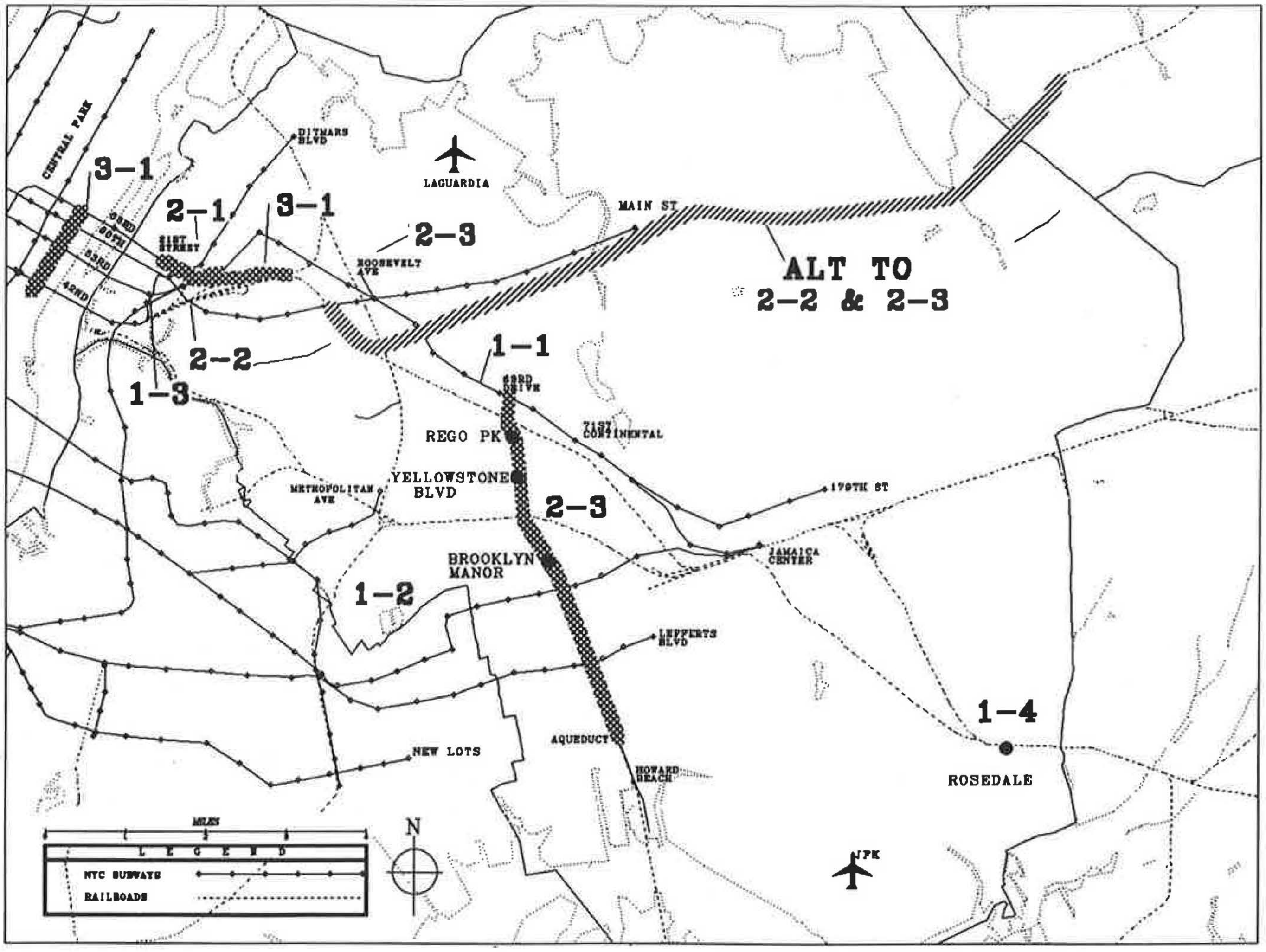


FIGURE 4 Queens-Manhattan Transit Development Program.

corridor over the next 25 years; it contains both short- and long-term proposals.

Short-Term Action (1990–1995)

The four low-cost short-term improvements should be implemented over the next few years in order to benefit travelers during Northern Boulevard construction.

1-1: 60-ft subway cars should be used on the E and F Queens Boulevard express trains instead of 75-ft cars to reduce dwell times at busy stations.

1-2: The J-Z service on the Broadway-Jamaica Line should be sped up by consolidating or closing lightly used, closely spaced stations.

1-3: Improved pedestrian connections should be provided in Long Island City between the IND Queens Plaza and the IRT-BMT Queensboro Plaza stations and between the IRT Court House Square stations.

1-4: A transit center should be developed at the Rosedale station of the LIRR in southeastern Queens.

Stage 2 Improvements (1995–2005)

The following improvements should be implemented by about the year 2005:

2-1: The express-local connection between the 63rd Street tunnel and Northern Boulevard should be built before the year 2000. This connection will allow the operation of 14 additional trains into Manhattan during the a.m. peak hour.

2-2: The 60th Street tunnel tracks serving Queensboro Plaza should be extended to connect with the Flushing Line express track by about the year 2000. This will allow the operation of an additional seven trains into Manhattan via 63rd Street and also increase the capacity of the Flushing Line express service by 50 percent. This extension will require the use of a car that can operate on both IRT and BMT tracks. This car should have extenders under each door that would operate on the 60th Street–Broadway Line. The stringent platform gap requirements of the Americans with Disabilities Act of 1991 may make this solution impractical; alternatively, gauntlet tracks could be provided at BMT stations in Manhattan.

2-3: A possible alternative by the year 2010 (if needed) would be to provide a fifth reversible track at Roosevelt Avenue and build a connection between the Queens Boulevard and a reactivated Rockaway Line. This would increase the number of Queens Boulevard express trains from 28 to 35. Under this concept, the E and F express trains would skip Roosevelt Avenue and the Rockaway express trains would use Roosevelt Avenue as a reservoir station, stopping and waiting for the next suitable interval between E and F trains.

The three projects represent an incremental approach to providing better subway service to Eastern Queens that permits full use of the 63rd Street tunnel; gives substantial relief to 53rd Street; provides additional capacity to northern, central, and eastern Queens; penetrates new markets; and provides faster service to the Rockaways.

Project improvements 2-2 and 2-3 contain some innovative operating concepts. If these concepts are unacceptable to NYCTA and MTA, an alternative concept should be implemented. This alternative concept involves converting the Port Washington Branch of the LIRR to NYCTA operation and connecting it to the upper level of the 63rd Street tunnel. Fourteen trains would operate to and from Manhattan via 63rd Street; seven express from Port Washington, and seven local from Little Neck. This option maximizes the use of the 63rd Street tunnel and provides better Manhattan distribution for Port Washington Branch passengers. It removes trains from the LIRR tunnel and creates track slots for the main line trains from Nassau and Suffolk counties.

Future Development (Post-2005)

A connection between the LIRR main line and the lower-level 63rd Street tunnel, along with extension of LIRR service to midtown Manhattan, has merit over the long run as part of regional transit improvements. This tunnel connection should initially terminate on 3rd Avenue around 50th Street, and should also provide for the ultimate extension across Manhattan into New Jersey because this would permit integrated regional commuter rail operations similar to the Reseau Express Regional (RER) system in Paris.

CONCLUSIONS

The analyses of the Queens transit improvement options in terms of cost, ridership, relief to existing subway lines, cost effectiveness, and related implications is a straightforward process. Provided that realistic estimates can be obtained for ridership and costs, the approaches used in this study have important transferability to other major rail transit proposals.

It is also clear from this analysis that deferring desirable projects in search of low-cost alternatives can be both counterproductive and costly in the long run. Therefore, it is essential to move ahead as soon as possible with the planned Northern Boulevard Connection. The needed funding for additional improvements can be obtained over the next several decades.

REFERENCES

1. *Queens Boulevard Subway Line Connection Supplemental Draft Environmental Impact Statement.* May 1990.
2. H. S. Levinson and R. A. Olmsted. *Queens-Manhattan Transit Improvements Study—Final Report.* UMTA-NY-06-0150-91-1. Transportation Training and Research Center, Polytechnic University, Brooklyn, N.Y., Aug. 1991.

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

Model To Estimate Passenger Origin-Destination Pattern on a Rail Transit Line

SHINYA KIKUCHI AND VIJAY PERINCHERRY

A method that develops a passenger origin-destination (O-D) table for a transit line is presented. The input to the model is the boarding and alighting counts at stations, and the output is the estimated passenger volume for each station pair. The model can make use of the analyst's knowledge of passenger volumes for selected station pairs if it is available in an approximate range. The O-D volumes are estimated to minimize the expected error by locating each estimate as close to the center of the feasible solution space as possible; this is accomplished by a linear programming method. The estimates can be revised iteratively by incorporating the analyst's knowledge of the passenger travel pattern. Examples include the case for which only the nondirectional boarding and alighting counts are available.

The boarding and alighting counts at stations and the origin-destination (O-D) travel pattern are the basic data for analyzing the demand for a transit line. These data provide the basic information of the number of passengers traveling between stations, which can be used to determine stopping schemes, fare structures, and schedules and to serve as the data for general system planning. The boarding and alighting counts at each station can be obtained without major difficulty as part of the routine activities of a transit agency. The O-D volumes (the number of passengers traveling between specific stations), on the other hand, are not easy to obtain. They require more-elaborate surveys of tracking passengers from their boarding stations and alighting stations. Such surveys are generally expensive to conduct, and accuracy depends on the sample size. For transit lines with many passengers—such as rail rapid transit lines—subjectively estimated passenger trip patterns, perhaps in the form of a range, may be available for selected station pairs based on past surveys and the experience of the analyst. In this paper, we propose a method that develops an estimated O-D table of a transit line using approximate information of selected O-D pairs as well as the boarding and alighting counts.

Mathematically, the proposed method estimates the elements of a passenger O-D table by solving an indeterminate system of linear equations and inequalities. The set of linear equations represents the conservation of flow equations based on the boarding and alighting counts, and the set of linear inequalities represents the information on some of the unknown parameters given by ranges of values. The elements of the O-D table are derived to minimize the expected error between "true" value and predicted value. The expected error is minimized when the estimate is at the center of the feasible range of the true value. A measure that indicates how close an estimate is to the center of the feasible range is developed. For each estimate, its closeness to the midpoint is measured, and the sum of the measures is maximized using a linear programming formulation.

Civil Engineering Department, University of Delaware, Newark, Del. 19716.

The proposed model is suited for estimating an O-D pattern for a heavily used transit line, in which the analyst has a general idea about discernible flow pattern of certain station pairs, based on general knowledge, previous surveys, and planning data. The method is characterized by its ability to estimate an O-D table based on the boarding and alighting counts at stations and estimated ranges of O-D volumes for some pairs. The method can also be used to estimate a bidirectional O-D table when the boarding and alighting counts are available only for the total of the bidirectional movement; for example, the data collected at the fare gates of rail transit stations.

PREVIOUS WORK

Similar problems are found among papers dealing with the development of an O-D table in four subjects: the context of the travel demand forecasting process, the passenger travel pattern on a transit line, intersection turning volumes, and freeway travel patterns. The goal common to all applications is the identification of the elements of the O-D matrix given the row and column totals (trip generation and attraction) and the information on the elements of the matrix. In developing the O-D table of a transit line, the approaches may be grouped into two types: one based on the improvement of a "seed" (or a priori) O-D matrix; and the other, which does not use the seed matrix, based on the analogy to the fluid flow.

Ben-Akiva et al. compared iterative proportional fitting (IPF), constrained generalized least-squares method (CGLS), constrained maximum likelihood estimation (CMLE), and fluid analogy method using the actual transit ridership data (*1*). The first three methods require a seed matrix, and the elements of the seed matrix are iteratively revised to satisfy the conservation of flow principle. The IPF method revises the value of the elements iteratively to obtain a balance between the boarding and alighting counts. Furth also applied this method to estimate intersection turning movements and compared the estimates and the observed values (*2*). The CGLS and CMLE methods make certain assumptions about the relationship between the true value and the sampled value and solve optimization models that take into account the conservation of flow. A large number of models and discussions are presented on the estimation of an O-D table in the context of travel demand forecasting, including entropy maximization and minimization of information (*3*), maximum likelihood (*4*), and generalized constrained least-squares model (*5*).

The fluid analogy method requires no seed O-D table; it uses only the boarding/alighting counts. It assumes a certain rule by which boardings and alightings are related at each station. At a station, passengers are equally likely to alight after they have traveled on the vehicle for at least a minimum distance. The ratio between the actual number of alightings and the total passengers eligible to alight is applied to the boarding passengers at each of the previous stops to determine the O-D pattern. Simon and Furth also show an application of the fluid analogy method to estimate an O-D table of a bus line (*6*). Furth further studied the procedure of updating an O-D table by multiproportional method after obtaining the initial matrix by the fluid analogy method (*7*). Although the fluid method is simple, straightforward, and easy to apply, its problem is the rigidity of the assumption. It lacks the mechanism to consider the travel pattern unique to a line. Another problem is that it cannot logically be applied to the case of a bidirectional O-D table; in other words, the input data must be the directional boarding/alighting counts. If the boarding/alighting counts are made at rail transit stations and directional separation of counts is not possible, applicability of the fluid analogy to rail transit O-D table development is questionable.

Additional literature on estimating an O-D table of a linear movement pattern without a seed matrix includes works by Stokes and Morris, who use simplified maximum likelihood estimates on a two-way contingency table (*8*), and Nihan and Davis, who show, among several approaches, a nonrecursive ordinary least-squares model for estimating the trip pattern on a freeway based on in-out counts at ramps (*9*). It requires the operation of the inversion of a large matrix and many total sets of data on total boardings and alightings along the line.

None of the models described above has the ability to incorporate the approximate information that the analyst may be able to provide. The effective use of such information requires a model that can incorporate approximate seed volumes for some O-D pairs in addition to boarding and alighting counts. The approximate volumes may be in the form of a range of values; for example, "10 to 50 percent of passengers boarding at Station A travel to B," or "less than (or more than) 60 percent of the passengers boarding at Station A should travel to B." A process that interacts with the analyst and incrementally improves the solution is also desirable. For example, if some elements of the derived O-D table do not look reasonable, the analyst can generate a second O-D table after revising the initial ranges of estimates.

PROBLEM AND BASIC EQUATIONS

Problem

For a transit line with a fixed number of stations, one-way passenger volume for every station pair is to be estimated for a given period. The following data are known to the analyst:

1. The numbers of boardings and alightings at each station for one direction of vehicle movement for the period in question (later we will show an example in which the boarding and alighting counts are available only for two-way volume).
2. Some knowledge of the O-D pattern of the passengers using the line. The degree of the analysts' knowledge may vary among the station pairs. For certain station pairs they may be confident, whereas for some other pairs they may not have any idea. The knowledge of the travel pattern for some station pairs may be expressed as "Between x and y percent of the passengers boarding at Station A travel to Station B." If no knowledge is available, the range is "between 0 and 100 percent."

Basic Equations

Consider one direction of vehicle movement on a transit line that has n stations, including both terminals, and denote a_{ij} as the number of passengers boarding at Station i who travel to Station j. The number of passengers alighting at Station j must be equal to the sum of the passengers who board at prior stations and travel to Station j, and each passenger who boards at Station i must alight at one of the stations $i + 1$ to n. The following relationships exist between the boarding passengers and the alighting passengers (these may be called the conservation of flow equations).

$$\sum_{i=1}^{j-1} a_{ij} = Q_j \qquad \text{for } j = 2,3, \ldots, n \tag{1}$$

and

$$\sum_{j=i+1}^{n} a_{ij} = P_i \qquad \text{for } i = 1,2,3 \ldots, n-1 \tag{2}$$

where P_i is the number of passengers boarding at Station i during the analysis period, and Q_j is the number of passengers alighting at Station j for the same period.

The problem is to estimate the values of a_{ij}s that satisfy Equations 1 and 2. Since there are $n(n - 1)/2$ unknowns and $2(n - 1) - 1$ equations in Equations 1 and 2 (one of the equations can be derived from the remaining equation), a unique set of solutions can be obtained only when $n = 3$ (this is the case with one intermediate station). When n is greater than 3, the problem becomes an indeterminate system of linear equations; thus, normally, many sets of solutions exist.

If the approximate volumes are available for selected O-D pairs, they are expressed as ranges as follows:

$$s_{1(i,j)} \leq a_{ij} \leq s_{2(i,j)} \qquad \text{for } (i,j) = (1,2) \ldots, (n-1,n) \tag{3}$$

where $s_{1(i,j)}$ and $s_{2(i,j)}$ are lower and upper bounds of the estimated range for a_{ij}, respectively. If it is more realistic to assume that the range is given in percent of P_i, then $s_{1(i,j)}$ and $s_{2(i,j)}$ can be computed on the basis of the estimated percents of P_i. If no external bound is given to a_{ij}, the lower and upper bounds, $s_{1(i,j)}$ and $s_{2(i,j)}$ of a_{ij}, are determined by Equations 1 and 2 as

$$s_{2(i,j)} = \min\,[Q_j, P_i] \quad (4)$$

$$s_{1(i,j)} = \max\left[P_i - \sum_{k=i+1\,(k\neq j)}^{n} s_{2(i,k)},\ Q_j - \sum_{\ell=1(\ell\neq i)}^{j-1} s_{2(\ell,j)},\ 0\right] \quad (5)$$

We now have a problem that has $n(n - 1)/2$ unknowns, with $2(n - 1) - 1$ equations (Equations 1 and 2) and $n(n - 1)/2$ inequalities (Equation 3), which bind the solution space of the unknowns.

APPROACH

The problem is to solve for a_{ij} from the set of expressions that are Equations 1 through 3. Our approach is to identify the values for a_{ij} that would result in the least expected error between the true value and the predicted value. Before solving the problem, let us consider the following simple two-variable problem as an example.

Two-Variable Example

Suppose that the values of two parameters, x and y, are to be determined when the following conditions are given:

$$\alpha x + \beta y = w \quad (6)$$

$$a \leq x \leq b \quad (7)$$

$$d \leq y \leq e \quad (8)$$

where α, β, a, b, d, and e are constants greater than or equal to zero.

Graphically, the feasible region for x and y lies on the line segment AB shown in Figure 1. From Equations 6 through 8 combined, the values of x and y are bound by

$$v_{1x} \leq x \leq v_{2x} \quad (9)$$

$$v_{1y} \leq y \leq v_{2y} \quad (10)$$

The set of (x,y) values that corresponds to the midpoint of line AB represents the "safest" estimates for x and y because at this point the expected error from the true value is minimized. This expected error is the expected difference between the estimated and the true value, assuming that the location of the true value is unknown and anywhere between A and B. If the location of the true value is assumed to be uniformly distributed over the line AB, it can be proved that the expected value of the distance between the estimated and the true values is minimum when the estimate is at the center of the line.

Let us now introduce artificial variables c_x and c_y, which are defined as

$$0 \leq c_x \leq z_x \quad (11)$$

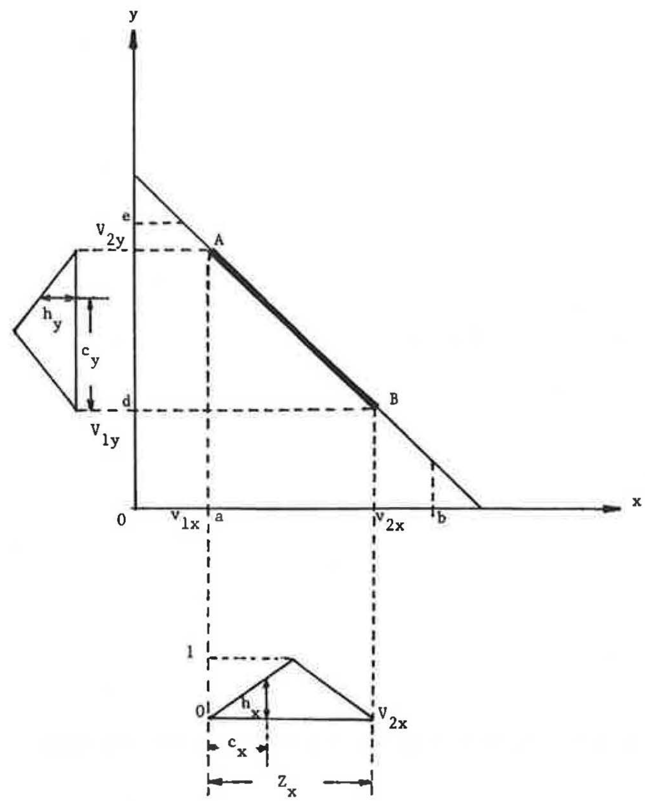


FIGURE 1 Feasible region and explanation of *h*.

$$0 \leq c_y \leq z_y \quad (12)$$

where

$$z_x = v_{2x} - v_{1x} \quad (13)$$

$$z_y = v_{2y} - v_{1y} \quad (14)$$

where z_x and z_y represent the sizes of the feasible regions of x and y, respectively. Our task is to locate the value of x and y as close to the middle of z_x and z_y, respectively, as possible.

Assume variables h_x and h_y, which represent the measure of how close the values of x and y are to the middle of z_x and z_y, respectively, and let h_x and h_y follow triangular functions, as shown in Figure 1. The functions peak at the middle of z_x and z_y and the peak values are 1.

Let us now express x and y as

$$x = v_{1x} + c_x \quad (15)$$

$$y = v_{1y} + c_y \quad (16)$$

The degree that x and y are close to the middle of the z_x and z_y is measured respectively by

$$h_x = \min\left\{\frac{2c_x}{z_x}, 2 - \frac{2c_x}{z_x}\right\} \quad (17)$$

$$h_y = \min\left\{\frac{2c_y}{z_y}, 2 - \frac{2c_y}{z_y}\right\} \quad (18)$$

Therefore, the values of x and y that are closest to the middle of z_x and z_y can be found by maximizing $h_x + h_y$ and also maximizing the minimum value of h_x and h_y. This forms the following linear programming (LP) problem:

Objective:

$$\max h_x + h_y \text{ and } \max\{\min(h_x, h_y)\} \tag{19}$$

subject to

$$\alpha(v_{1x} + c_x) + \beta(v_{1y} + c_y) = w \tag{20}$$

$$\frac{2c_x}{z_x} \geq h_x \tag{21}$$

$$2 - \frac{2c_x}{z_x} \geq h_x \tag{22}$$

$$\frac{2c_y}{z_y} \geq h_y \tag{23}$$

$$2 - \frac{2c_y}{z_y} \geq h_y \tag{24}$$

$$c_x, c_y, h_x, h_y \geq 0$$

In practice, the $\max\{\min(h_x,h_y)\}$ objective in Equation 19 can be accommodated by setting additional constraints of $h_x \geq h_z$ and $h_y \geq h_z$, where h_z is a threshold that defines the minimum value of h_x and h_y. The value of h_z is provided externally on a trial-and-error basis. The LP model here is identical to the formulation of fuzzy LP formulation in which satisfaction of the decision maker, as represented by h_z, is to be maximized under constraints.

Multivariable Formulation

We now expand the formulation to the problem defined by Equations 1 through 3. First, we redefine the boundary of the feasible region of each variable based on Equations 1 through 3 as

$$v_{1(i,j)} \leq a_{ij} \leq v_{2(i,j)} \tag{25}$$

Since a_{ij} appears once each in Equations 1 and 2, and all coefficients and the value of the right-hand side of the equations are positive, $v_{1(i,j)}$ and $v_{2(i,j)}$ can be systematically determined after incorporating the range defined in Equation 3.

We now introduce a slack variable, c_{ij} for a_{ij}, which corresponds to c_x (or c_y) in the two-variable example. This variable represents the distance between the lower boundary of the feasible range and the estimated value of the variable. Using the same approach as mentioned in the two-variable case, we define the slack variable, c_{ij}, for each a_{ij} as follows:

$$a_{ij} = v_{1(i,j)} + c_{ij}$$
$$0 \leq c_{ij} \leq z_{ij} \tag{26}$$

where z_{ij} [$= v_{2(i,j)} - v_{1(i,j)}$] is the size of the range of a_{ij}.

We then set up a function h_{ij} such that

$$h_{ij} = \min\left\{\frac{2c_{ij}}{z_{ij}}, 2 - \frac{2c_{ij}}{z_{ij}}\right\} \tag{27}$$

as was the case in Equations 17 and 18.

The value of h_{ij} is a measure of how close c_{ij} is to the center of [$v_{1(i,j)}$, $v_{2(i,j)}$]. The value of h_{ij} lies between 0 and 1, and the closer the value of h_{ij} is to 1, the closer the obtained a_{ij} is to the midpoint of the feasible range.

The formulation of the model that corresponds to Equations 17–22 is

$$\max \sum_i \sum_j \mathrm{h}_{ij} \tag{28}$$

subject to

$$\sum_i [v_{1(i,j)} + c_{ij}] = Q_j \qquad \text{for all } j \text{ (from Equation 1)} \tag{29}$$

$$\sum_j [v_{1(i,j)} + c_{ij}] = P_i \qquad \text{for all } i \text{ (from Equation 2)} \tag{30}$$

$$\frac{2c_{ij}}{z_{ij}} \geq h_{ij} \qquad \text{for all } i,j \text{ (from Equation 27)} \tag{31}$$

$$2 - \frac{2c_{ij}}{z_{ij}} \geq h_{ij} \qquad \text{for all } i,j \text{ (from Equation 27)} \tag{32}$$

$$h_{ij} \geq h_z \qquad \text{for all } i,j \text{ (from Equation 19)} \tag{33}$$

$$c_{ij}, h_{ij} \geq 0 \qquad \text{for all } i,j \tag{34}$$

The inputs to the above LP formulation are $v_{1(i,j)}$, Q_j, P_i, z_{ij}, and h_z, where constraint $h_{ij} > h_z$ in Equation 33 acts as $\max\{\min[h_{ij}$, for all $(i,j)]\}$, as defined in the second equation of Equation 19. h_z is an externally provided value ($0 < h_z < 1$). Equation 33 ensures that the minimum value of h_{ij} is greater than at least h_z. It is solved for c_{ij} and h_{ij}. The O-D volume, a_{ij}, is obtained by $v_{1(i,j)} + c_{ij}$, according to Equation 26. h_{ij} indicates the degree of closeness of a_{ij} to the center of the range.

The existence of the solution for this LP model depends on the range of the estimated value for c_{ij}, z_{ij}, as expressed in Equation 26. If the solutions cannot be obtained, a different range must be supplied or the current range should be relaxed, and the process should be repeated. If no range is given, other than the one determined by Equations 4 and 5, one should always get a set of solutions. This is the solution for which no external estimates are given.

To compensate for the possible error of the analyst's estimates, more than one analyst may be employed to provide different sets of estimated ranges, and the procedure discussed is repeated for each set of estimated ranges. The average of the results may be used as the aggregate measure of the passenger O-D pattern.

The procedure can be briefly summarized in the following eight steps:

1. Obtain the boarding (P_i) and alighting (Q_j) counts at each Station i.

2. Estimate the range of passenger volume for trips between i and j: minimum $v_{1(i,j)}$; the range z_{ij}. If the approximate range is not available, $v_{1(i,j)} = s_{1(i,j)}$ from Equation 5 and $z_{ij} = \min(P_i,Q_j) - s_{1(i,j)}$.
3. Determine acceptable value of h_z.
4. Formulate an LP model according to Equations 28 through 34, and solve for c_{ij}.
5. Prepare the O-D table. The O-D volume for the station pair $i-j$ is $v_{1(i,j)} + c_{ij}$.
6. Inspect the O-D table and identify the station pairs whose values do not match the analyst's subjective feeling.
7. Introduce new ranges for these O-D pairs (which may be based on subjective judgment), and adjust the ranges according to Step 2.
8. Repeat Steps 3 through 6 until the O-D volumes do not conflict with the analyst's observation and feeling.

EXAMPLES

The estimated O-D volumes of the proposed method are compared with the actual travel data of two transit lines: one, the Lindenwold line in Philadelphia, Pa., and the other, a new people-mover line in Yokohama, Japan. The results of the proposed model are also compared with the ones derived from the fluid analogy method.

Example 1: Lindenwold Line O-D Volume

In the Lindenwold line example, the estimated O-D matrix of the Lindenwold line is compared with the actual data obtained from the 1979 O-D survey. The Lindenwold line is a rail rapid transit line that traverses between Philadelphia and Lindenwold, New Jersey, and is operated by Delaware River Port Authority. There are 13 stations on the line including the two end stations. The travel pattern of the passengers focuses to and from Philadelphia; it collects passengers to Philadelphia for its westbound travel and distributes them from Philadelphia in its eastbound travel. The actual O-D data provided to us by Delaware River Port Authority (*10*) are adjusted from the sample survey of 3,226 counts, and the adjusted O-D table is a symmetric table with the total number of 40,532 daily trips in both directions, which was based on a sample survey of 3,226 passengers.

A model is constructed according to the formulation shown in Equations 28–34. The O-D table of the line is estimated by more than one run of the LP model. Starting with the case that has no information other than the boarding and alighting counts at each station, each run incorporates additional information on the estimated range for c_{ij} for selected (i,j) pairs.

The following runs were tested:

Run 1. Run 1 is based on the boarding and alighting counts only—all P_is and Q_js (no subjective estimates for a_{ij}) only. Having obtained results from run 1, the O-D volumes for selected station pairs that do not appear reasonable are adjusted based on partial information for those station pairs; ranges of values considered are based on the general travel patterns obtained from the total boardings and the total alightings. The following ranges (in proportion of the total boarding at i) are incrementally incorporated for each of the subsequent runs:

Run 2. $0.2 \leq (a_{i,13}/P_i) \leq 1.0$, for all i; and data for Run 1.
Run 3. $0.1 \leq (a_{i,8}/P_i) \leq 1.0$, for all i; and data for Run 2.
Run 4. $0.15 \leq (a_{i,11}/P_i) \leq 1.0$, for all i; and data for Run 3.

These values of the ranges are determined considering the number of alightings at Stations 13, 8, and 11. For example, Station 13 has the highest proportion (approximately 25 percent: 5,162 ÷ 20,264) of the passengers alighting; thus, a rough range of "greater than 20 percent or $0.2 \leq a_{i,13}/P_i \leq 1.0$" is selected for Run 2. Similarly, the subsequent runs incorporate additional ranges to selected elements on the basis of the boarding and alighting counts at stations.

Table 1 compares the actual volumes with the result of Run 4, the upper value of each cell being the result of Run 4 and the lower value being the actual volume. Table 2 shows the changes in the accuracy of the estimates as additional information, represented by the ranges in each run, is incorporated. It is seen that the number of matrix elements within a given margin of error increases as more information is incorporated. In Run 4, all elements are within the margin of error of 500 (which is less than 2.5 percent of the total passenger volume).

Table 2 also compares the results of the fluid analogy method with those of Runs 1, 2, 3, and 4 of the proposed model. The performance of the two methods is compared using the values of the correlation coefficient and the slope of the least-squares fit for the relationship between the actual and estimated values. With each run, the result of the proposed model improves, but the fluid analogy method yields a slightly better set of estimates than the proposed method (under Run 4) based on the performance indicators. This improvement may be attributed to the fact that the travel pattern of the eastbound Lindenwold line is similar to the fluid flow from a high point to low points, because most passengers board at stations in Philadelphia (Stations 1 through 4) and travel to the remaining stations.

Example 2: Yokohama's Transit Line

A second example is based on the O-D data of a newly built automated people-mover system in Japan. The system is outside Yokohama, and it has 14 stations including the end stations. Both end stations are connected to the stations of a heavily used rail transit line. Unlike Lindenwold line, a one-way movement of the train performs two major functions: it distributes passengers from the starting terminal to the stations on the middle of the line, and it collects passengers from these middle-of-the-line stations and transports them to the other terminal. The O-D data (surveyed December 14, 1989), were obtained from the computerized ticket validation counts.

An analysis similar to that of Example 1 is performed for this line. Because in this case we have the complete actual O-D data, we tested three cases: each direction of movement separately and both directions combined. The following are the inputs used for the runs.

TABLE 1 LINDENWOLD LINE: 1979 O-D DATA EASTBOUND

	Destination Stations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
1	0	0 0	2 4	60 103	7 12	404 256	219 180	1250 1237	504 607	994 701	1100 1104	548 939	1811 1760	6903
2		0	2 0	51 17	1 5	85 167	64 118	500 497	132 213	149 278	400 409	628 331	700 679	2714
3			0	9 1	1 0	58 34	58 37	150 161	58 90	58 81	100 97	135 117	150 162	780
4				0	9 2	568 680	426 494	1192 1170	882 553	594 713	1167 1166	928 958	1500 1533	7269
5					0	19 0	19 14	55 83	20 29	20 23	40 40	20 5	70 70	264
6						0	63 9	50 49	106 199	106 137	225 215	365 275	500 533	1417
7							0	8 7	48 67	48 27	90 91	147 151	300 298	641
8								0	13 11	13 20	35 36	17 15	100 97	179
9									0	4 7	10 9	24 23	10 10	49
10										0	7 8	19 22	10 9	37
11											0	1 0	10 11	11
12												0	0 0	0
13													0	0
	0	0	4	121	19	1137	852	3204	1769	1989	3175	2836	5162	20,264

Notes: The upper number in each cell is the estimated O-D volume for Run No. 7.
The lower number in each cell is the actual O-D volume.

TABLE 2 SUMMARY OF PERFORMANCE OF MODEL

	Cumulative Number of Elements within Margin of Error (E)[1]						Performance measure Actual vs. Estimated	
	E≤20	E≤50	E≤100	E≤500	E≤1000	E≤2000	Correlation[2] Coefficient	Slope[3]
Lindenwold-Westbound (Total elements 78)								
LP Model Run 1	34	45	58	76	78	–	0.911	0.899
LP Model Run 2	36	49	59	77	78	–	0.911	0.897
LP Model Run 3	41	54	64	77	78	–	0.931	0.924
LP Model Run 4	44	65	70	78	–	–	0.976	0.974
Fluid Analogy Model	45	62	68	78	–	–	0.984	0.988
Yokohama-Westbound (Total elements 91)								
LP Model Run 1	54	66	73	90	90	91	0.773	0.684
LP Model Run 2	69	84	90	91	–	–	0.987	0.975
Fluid Analogy Model	61	74	82	91	–	–	0.928	0.921
Yokohama-Eastbound (Total elements 91)								
LP Model Run 1	55	65	70	90	90	91	0.752	0.698
LP Model Run 2	66	83	85	91	–	–	0.984	1.022
LP Model Run 3	67	83	88	91	–	–	0.977	0.991
Fluid Analogy Model	63	73	83	90	91	–	0.928	0.942
Yokohama-Both Direc. (Total elements 182)								
LP Model Run 1	122	137	143	179	180	182	0.822	0.813
LP Model Run 2	127	145	157	181	182	–	0.923	0.903
LP Model Run 3	131	150	162	182	–	–	0.955	0.938

Notes: 1. E = |actual volume – (minus) estimated O-D volume|

2. Correlation coefficient of the regression line of the relationship between the actual and estimated volumes.

3. Slope represents the gradient of the regression line (y=ax).

- Westbound

Run 1. Boarding and alighting counts at all stations (all P_s and Q_js).

Run 2. $0.05 \leq (a_{1,14}/P_i) \leq 0.15$, and data for Run 1.

- Eastbound

Run 1. Boarding and alighting counts at all stations (all P_is and Q_js).

Run 2. $0.1 \leq a_{14,1}/P_{14} \leq 0.3$, and data for Run 1.

Run 3. $0.5 \leq a_{14,6}/P_{14} \leq 1.0$, and data for Run 2.

- Bidirectional

Run 1. Boarding and alighting counts at all stations (all P_is and Q_js).

Run 2. $0 < a_{1,14}/P_i < 0.2$, $0 < a_{14,1}/P_{14} < 0.2$, and data for Run 1.

Run 3. $0.1 < a_{6,14}/P_6 < 0.4$, $0.1 < a_{8,14}/P_8 < 0.4$, and data for Run 2.

To determine the ranges shown subjectively the distributions of total alighting volumes and boarding volumes are examined. The results of the runs are shown in Table 2. In all cases, as more information on selected O-D pairs is incorporated, the accuracy of the estimate improves significantly; particularly, the change in the performance from run 1 to run 2 is significant. Run 2 of the westbound O-D table is a result incorporating a range to only one element (*1,14*). Table 3 shows the estimated and actual O-D tables for the westbound and the eastbound movements separately. The upper value of each cell is the estimated value, and the lower value is the actual value. The estimated volumes for the westbound are based on the results of Run 2 and for the eastbound, Run 3.

As for Example 1 (the Lindenwold line), we compare the estimates obtained using the proposed method with those obtained using the fluid analogy method in Table 2. In this example, the estimates using the proposed method are found to perform better than those using the fluid analogy method in terms of the number of elements within a given margin of error and the performance measures. As seen in Table 2, the results of the coefficient of correlation and the slope of the least-squares fit for the relationship between the actual and estimated volumes indicate that the proposed model (after additional information) yields better estimates than the fluid analogy method. This may be caused by the unique passenger travel characteristics of this line, as described, which has a less "fluid" passenger flow pattern. In addition, a bidirectional O-D table was estimated by the proposed model using the total boarding/alighting counts at each station. The results

TABLE 3 YOKOHAMA PEOPLE-MOVER O-D TABLE (ESTIMATED AND ACTUAL)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
1		368 368	924 928	844 849	970 919	992 1025	819 846	861 877	497 577	13 25	91 131	125 163	90 188	1096 797	7690 7693
2	400 400		14 11	14 9	14 18	14 17	14 10	14 8	14 4	3 0	14 4	14 5	14 13	48 98	599 597
3	1011 1056	53 9		33 34	33 63	33 38	33 16	33 15	33 24	2 2	16 17	23 23	28 31	170 178	1507 1506
4	720 763	8 7	78 38		24 43	24 7	24 27	24 50	24 33	2 1	17 15	23 15	24 32	138 106	1140 1137
5	975 942	8 11	24 58	18 16		36 15	36 47	36 18	36 28	2 2	16 16	23 25	28 22	271 294	1519 1517
6	1135 1147	8 9	24 22	17 12	23 20		35 18	35 55	35 46	2 1	16 15	23 23	28 22	295 294	1686 1684
7	645 888	8 9	24 32	58 30	123 41	157 18		33 16	41 12	2 1	16 12	23 20	28 20	300 366	1470 1465
8	823 853	8 8	24 44	17 29	24 59	28 61	139 17		46 6	2 1	16 10	23 18	28 26	502 560	1690 1692
9	589 608	8 4	24 13	17 37	24 58	28 43	20 25	75 8		2 1	16 5	23 12	28 12	308 350	1173 1176
10	18 22	2 0	2 1	2 1	2 5	2 3	2 2	1 1	5 2		1 1	1 4	8 2	12 17	58 61
11	107 104	8 5	11 20	11 15	11 25	11 17	11 13	10 10	33 6	1 0		6 5	37 8	44 76	301 304
12	139 130	8 3	14 28	14 14	14 20	14 21	14 23	14 19	22 15	1 3	24 3		35 7	35 63	348 349
13	178 165	8 15	18 27	17 22	18 28	18 27	18 20	18 25	15 13	12 0	17 9	17 5		211 211	565 567
14	965 646	38 90	246 209	171 167	239 223	312 382	204 309	306 364	226 266	16 29	41 71	67 80	175 175		3006 3011
Total	7725 7724	543 538	1432 1431	1233 1235	1519 1522	1682 1674	1369 1373	1465 1466	1037 1032	60 66	304 309	391 398	551 558	3430 3433	

Notes: 1. The upper right matrix represents the westbound movement
2. The lower left matrix represents the eastbound movement
3. The upper number of each cell is the estimated value and the lower number is the actual O-D volume
4. For westbound (Stations 1→14) movement, the estimated values are the results of Run 2
5. For eastbound (Stations 14→1) the estimated values are the results of Run 3
6. Due to rounding of estimated volumes there are slight differences between the sums of actual and estimated volumes on each

of the correlation analysis between the actual and estimated O-D volumes for this case are also shown in Table 2. A comparison with the fluid analogy method is not performed because the fluid analogy cannot logically be applied to the bidirectional case.

CONCLUSIONS

This paper has presented a method that estimates the O-D pattern of passenger travel along a transit line. The input to the model is the boarding and alighting counts at each station and estimated ranges of passenger O-D volumes for selected station pairs. The estimated ranges may be given by an analyst who is familiar with the O-D pattern along the line. The ranges may also be inferred from past O-D surveys, from analyst observation, or from values derived by other O-D estimating methods. Although the proposed method is an approximate method, the examples demonstrate that it can yield reasonably accurate estimates of the O-D pattern and at least the same level of accuracy as the fluid method. Unlike the fluid method, the proposed method can improve the estimates based on incomplete information on the O-D pattern. It is particularly interesting to notice how quickly the estimates improve by incorporating loose ranges on only one or two O-D pairs.

The method solves an indeterminate system of linear systems with the aid of information on the ranges of the values of selected unknown parameters. The advantage of the proposed method is that analysts can incorporate estimated O-D information (in a range) for only those pairs for which they have some confidence. The method is also suited for the transit lines in which the fluid analogy travel pattern is hard to justify, such as the case of bidirectional O-D.

The method can be used not only for estimating the O-D table of a transit line but also for a number of other applications; for example, (a) the distribution of the duration of stay at a parking lot can be estimated for the counts of vehicles entering and exiting the lot over the period; (b) the vehicle travel pattern along a freeway or an arterial can be estimated from the traffic counts at entrances and exits at the ramps or at intersections; and (c) the characteristics of the bypass traffic can be estimated for a small city when the inbound and outbound traffic volumes on each of the roads leading to the city are known and the planner supplies the estimated values of the bypass traffic between two road pairs. In general, the method determines the cause-and-effect relations of a system: the causes are passenger boardings at various stations, and the effects are the alightings at various stations. The travel pattern derived is the relationship between these boardings and alightings.

REFERENCES

1. M. E. Ben-Akiva, P. P. Macke, and P. S. Hsu. Alternative Methods to Estimate Route Level Trip Tables and Expand On-Board Surveys. In *Transportation Research Record 1037*, TRB, National Research Council, Washington, D.C., 1985, pp. 1–11.
2. P. G. Furth. A Model of Turning Movement Propensity. In *Transportation Research Record 1287*, TRB, National Research Council, Washington, D.C., 1990.
3. H. J. Van Zuylen and L. G. Willumsen. The Most Likely Trip Matrix Estimated From Traffic Counts. *Transportation Research*, Vol. 14B, 1980, pp. 281–293.
4. H. Spiess. A Maximum Likelihood Model for Estimating Origin-Destination Matrices. *Transportation Research*, Vol. 21B, No. 5, 1987, pp. 395–412.
5. C Hendrickson and S. McNeil. Estimation of Origin-Destination Matrices with Constrained Regression. In *Transportation Research Record 976*, TRB, National Research Council, Washington, D.C., 1984, pp. 25–32.
6. J. Simon and P. G. Furth. Generating a Bus-Route O-D Matrix from On-Off Data. *Journal of Transportation Engineering*, Vol. 111, No. 6, 1985, pp. 583–593.
7. P. G. Furth. Updating Ride Checks with Multiple Point Checks. In *Transportation Research Record 1209*, TRB, National Research Council, Washington, D.C., 1989, pp. 49–57.
8. R. W. Stokes and D. E. Morris. Application of an Algorithm for Estimating Freeway Trip Tables. In *Transportation Research Record 976*, TRB, National Research Council, Washington, D.C., 1984, pp. 21–23.
9. N. L. Nihan and G. A. Davis. Recursive Estimation of Origin-Estimation Matrices from Input/Output Counts. *Transportation Research*, Vol. 21B, No. 2, 1987, pp. 149–163.
10. *Lindenwold Line Passenger Survey*, Volume 1. UMTA Project IT-09-0073. Delaware Valley Regional Planing Commission, 1979.

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

Statistical Summary of Operating North American Commuter Rail Services

GEORGE E. GRAY

The results of a survey of major established commuter rail services in the United States and Canada are presented. The survey was needed for comparable operating statistics to help justify a commuter rail service fare increase for the Peninsula Commute Service (Caltrain). The limits of use of the reported data, observations on the results, and identification of possible further research needs are discussed. The reported data were used in implementing a fare increase for the Caltrain service in 1991 and will also be used to indicate areas for improvements in efficiency and effectiveness of Caltrain operations in the future.

Commuter rail is defined as "a passenger railroad service that operates within metropolitan areas on trackage that usually is part of the general railroad system. The operations, primarily for commuters, are generally run as part of a publicly owned regional system or by a railroad company as part of its overall service. In some areas it is called regional rail (*1*, p. 65)." The terms "commuter rail" and "regional rail" will be used interchangeably to identify the same services.

Commuter rail services in North America are growing at a healthy pace both in ridership for the older systems and in the number of operations. In recent years, new services have been implemented in Florida, Ontario (Canada), and California. Several factors fuel this growth, including congested highways, increased motor fuel costs, air quality concerns and spreading suburbanization, which is often a function of housing costs and perceived-quality-of-life choices. Interest in this mode of urban travel is continuing to increase, and indications are that many new and expanded services will be added to the commuter-rail inventory in the 1990s.

To study the feasibility of new or added commuter rail services, it is useful to estimate the full range of costs and revenues associated with the proposals. At present, aggregated costs and operating data of the existing services are scarce. UMTA's—now the Federal Transit Administration (FTA)—report *Compendium of National Urban Mass Transportation Statistics* (*2*) is based on reported transit operating statistics as required by Section 15 of the UMTA/FTA statutes. This report provides basic information, however, not enough data are available to identify opportunities for improving the efficiency of existing commuter rail services or for analyzing the feasibility of new or expanded services.

The American Public Transit Association's *1990 Transit Operating and Financial Statistics* (*3*) is almost the same as the UMTA Section 15 report and is not, in the judgment of many, adequate for service feasibility studies.

California Department of Transportation, P.O. Box 7310, San Francisco, Calif. 94120.

The research into the operating statistics of existing commuter rail services reported herein was used to fill the need for such data. It also served the more immediate need of gathering statistical information on the North American commuter rail services so that comparison data relating to the fare structure of the Peninsula Commute Service (PCS or Caltrain), which operates in California between San Francisco and San Jose, could be obtained. The basic problem and need for this information was that the Caltrain service, by legislative mandate, is to operate at a minimum revenue recovery ratio of 40 percent, based on an income-cost definition established by legislation, which is considered very restrictive and more constrained than any other in the industry. For instance, operator incentive payments, advertising, property taxes, and insurance are all charged to operating expense under the definition established in the current California statutes (*4*).

With the late 1990 Mideast crisis and its resulting fuel cost fluctuations, the PCS recovery ratio was calculated at about 38 percent, with contributed local funds used to increase the income up to the required 40 percent level. Although efforts to reduce the operating costs continued, it was apparent that until the service was operated directly by those paying the costs, thereby reducing many of the expenses caused by contracting through the Southern Pacific Transportation Company, the opportunities to reduce costs in the short term would be few. This was especially true in the face of unstable fuel prices and existing Southern Pacific labor agreements.

The obvious alternative to lowering costs was to raise fares, which had been static since 1982 at about \$0.06/passenger-mi. A fare increase is never welcome, to management or to user, but there was little option because there were no signs of increased federal or state subsidy.

SURVEY NEED

In the late 1970s, the state of California opposed the proposed service abandonment by the Southern Pacific of the San Francisco–San Jose commute service. This ultimately resulted in a contract, beginning July 1, 1980, between the state and the Southern Pacific for continuing the service. This contract provided for a 10-year service continuation with options for contract extension. As the initial 10-year period drew to a close, the state informed local governments of its intent to turn the service over to local control. A joint powers authority was formed and was composed of representatives of the three counties involved (San Francisco, San Mateo, and Santa Clara). This authority began discussions with the Southern Pacific toward purchase of the service and was successful in obtaining legislation to extend the state responsibility for the management of the service until June 30, 1992, giving the authority time to negotiate for the purchase of the rights-of-way.

To provide service continuity, an extension to the original state management contract was consummated in June 1990. This extension provided for a service discontinuance on 90-day notice by either party with such notice to be given no sooner than March 1, 1991. On January 2, 1991, the joint powers authority and the railroad executed a letter of agreement covering the terms and conditions for the purchase of the rights-of-way. It is anticipated that this proposed sale will have been completed by June 30, 1992.

Because the state expects to relinquish the service to the joint powers agency or its successor by no later than June 30, 1992, and has a cost-sharing agreement with them, any fare increase must include agreement from the transit authorities of the three counties (Muni for San Francisco, SamTrans for San Mateo County, and the Santa Clara County Transit Authority). The best marketing strategy for a fare increase would be to present evidence that Caltrain was operating efficiently and that user costs were comparatively low.

After consulting the existing commuter rail cost data and finding them inadequate for the intended purposes, a survey requesting information from all the readily identified major North American commute rail operations was initiated.

Seventeen requests were sent out in September 1990. The request packet included data and information covering the Caltrain operation, a filled-in form covering Caltrain, and a blank form for the requested data. These items are shown in Figure 1. Several of the 17 requests were known duplications. For example, in the Chicago area, inquiries were sent not only to Metra but also to the Regional Transit Agency (RTA) and the railroads that provide service for Metra. The goals of the survey were to obtain adequate information adequate to use as

1. A report card for existing services,
2. An indication of the health of particular commuter rail services, and
3. An indication of cost and revenue levels expected from such services.

SURVEY RESULTS

Results were ultimately obtained from all of the major commuter rail services in the United States and Canada. The results covered nine major urban areas in North America. Several services were not included in the subsequent statistical analysis either because of their newness or because of their demise during the reporting period, which was generally FY 1990. The resulting statistics are presented in Table 1. This table also provides specific information on Caltrain and, for comparison purposes, the San Francisco Bay Area Rapid Transit (BART) service. Table 2 presents service information and operating statistics on the eight services that reported.

Caution is urged in using this information because no attempt has been made to ensure that the data are based on uniform definition and each service should be judged on its own particular circumstances. For example, operating costs cited are as reported by the respective services, yet there is

Name of service: Peninsula Commute Service (Caltrain)
Provider: State of California - Caltrans
Operator: Southern Pacific Transportation Company
Service area: San Francisco - San Jose
Reporting year: 1989-90 Fiscal Year
Miles of line(s): 46.9 miles
Trains/work day: 52
Trains/Saturday: 26
Trains/Sunday: 20
Passengers/year: 6.35 million
Passenger-miles/year: 148.75
Train-miles/year: 727,231
Operating cost/year: $27.75 million
Farebox revenue/year: $9.42 million
Total revenue/year: $10.68 million
Seat-miles/year: 358.85 million
Operating cost/passenger: $4.37
Fare revenue/passenger: $1.48
Total revenue/passenger: $1.68
Operating cost/passenger-mile: $0.19
Fare revenue/passenger-mile: $0.06
Total revenue/passenger-mile: $0.07
Passengers/car-mile: 2.60
Passenger-miles/train-mile: 204.55

FIGURE 1 Sample of commuter rail service survey.

reason to believe that the differentiation between capital and operating costs is not uniform.

The Caltrain service offers an example of keeping the service characteristics in mind when using such gross data. The Caltrain service does not adequately serve its major market, the central business district of San Francisco. A "typical" patron drives to the Caltrain depot, pays a modest parking fee, rides an average 23.4 mi, and catches a Muni bus to a workplace 2 mi from the Caltrain San Francisco station, so the passenger is paying more than the train fare. There is a Peninsula Pass honored by the four major transit systems serving the peninsula, but neither the pass cost nor the parking charges are reflected in these reported costs.

In addition, no attempt has been made to group the services to ascertain possible cost differences that result from such basic factors as source of power, (i.e., electricity or diesel fuel), labor rule requirements, or salary levels for the reporting services. For example, the labor cost for engineers of the Caltrain service at $25.97/hr is the highest amount reported for any commuter rail service (*5*, p. 6).

OBSERVATIONS

Although caution is urged in using these results, certain observations can reasonably be made from Table 1.

1. A service range of 14 to 30 mi, as reflected in the average trip length information, can be a valuable indicator of the possible demand service range. This range indicates where marketing may have maximum effect.
2. The operating cost per passenger range of 100 percent ($4 to $8) may be largely a function of the differences in power source, labor costs, meld of single trip and commuted fares, and charges for using the track. To obtain expected costs for proposed new systems, a detailed analysis is necessary.
3. Data on fare revenue per passenger coupled with trip length information indicates that the present market will ac-

TABLE 1 SUMMARY OF OPERATING STATISTICS[a] AND COSTS FOR NINE NORTH AMERICAN PROPERTIES[b] (REPRESENTING NEW YORK, NEW JERSEY, TORONTO, CHICAGO, BOSTON, PHILADELPHIA, WASHINGTON, D.C./BALTIMORE, SAN FRANCISCO/SAN JOSE)

	Range	Average	PCS	BART[c]
Average trip length	13.9-29.4 mi	22.0 mi	23.3 mi	12.6 mi
Operating cost per passenger	$4.07-$8.00	$5.28	$4.37	$2.74
Fare revenue per passenger	$1.48-$3.54	$2.51	$1.48	$1.40
Operating costs per passenger-mile	$0.17-$0.44	$0.26	$0.19	$0.20
Fare revenue per passenger-mile	$0.06-$0.17	$0.12	$0.06	$0.11
Total revenue per passenger-mile	$0.07-$0.19	$0.125	$0.07	$0.12
Passengers per car-mile	1.31-2.60	1.75	2.60	unknown
Passenger-miles per train-mile	75.5-337.0	191.5	204.6	unknown
Revenue recovery ratio[d]	38%-62%	50%	38%	55%

[a]Total passengers per year: 272 million.
[b]Properties and year of reported statistics: Long Island RR (F.Y. 1989), New Jersey Transit (F.Y. 1990) GO Transit (F.Y. 1990), Metra RTA (Calendar 1989), NICTD (Calendar 1989), MBTA (F.Y. 1990), PCS (F.Y. 1990), SEPTA (F.Y. 1990), MARC (F.Y. 1990).
[c]BART statistics ('90 F.Y.) are not included in the Range and Average computations.
[d]Total revenue divided by operating cost.
Note: Problems in definition of terms may exist, see text.

TABLE 2 STATISTICAL SUMMARY OF COMMUTER RAIL SERVICE

	PCS	SEPTA	LIRR	GO Tran.	Metra	MBTA	NJT	MARC
Reporting year	'90 F.Y.	'90 F.Y.	'89 F.Y.	'90 F.Y.	1989	'90 F.Y.	'90 F.Y.	'90 F.Y.
Miles of line(s)	47	282	595	245	424	244	781	151
Trains/workday	52	360	732	145	598	373	569	64
Trains/Saturday	26	248	465	75	269	136	256	0
Trains/Sunday	20	173	471	62	135	68	216	0
Passengers/year (millions)	6.4	25.7	75.4	24.0	67.8	19.2	46.9	3.5
Passenger-miles/year (millions)	149	357	2019	456	1415	348	1020	103
Train-miles/year (millions)	0.73	4.73	7.61	1.35	5.74	2.60	6.68	0.61
Operating cost/year (millions $)	27.8	157.9	603.1	179.1	275.4	88.6	279.8	17.2
Farebox revenue/year (millions $)	9.4	61.1	266.7	86.5	142.8	unknown	143.2	10.1
Total revenue/year (millions $)	10.7	66.3	288.2	95.2	163.7	33.3	173.6	10.2
Seat-miles/year (millions)	359	1443	6917	1979	4551	1500	4397	267
Operating cost/passenger ($)	4.37	6.15	8.00	4.09	4.07	4.61	5.96	4.98
Fare revenue/passenger ($)	1.48	2.38	3.54	2.51	2.11	1.74	3.05	2.92
Total revenue/passenger ($)	1.68	2.58	3.82	2.68	2.42	1.74	3.70	2.95
Operating cost/passenger-mile ($)	0.19	0.44	0.30	0.28	0.20	0.25	0.27	0.17
Fare revenue/passenger-mile ($)	0.06	0.17	0.13	0.14	0.10	0.10	0.14	0.10
Total revenue/passenger-mile ($)	0.07	0.19	0.14	0.16	0.12	0.10	0.17	0.10
Passengers/car-mile	2.60	2.07	1.31	1.96	2.30	1.46	1.33	1.34
Passenger-miles/train-mile	204.6	75.5	265.5	337.0	246.5	135.4	152.7	169.0

Note: Problems in definition of terms may exist, see text.

cept a fare of approximately $0.115/passenger-mi. This charge is a bargain for the single-occupant automobile driver and the two-occupant automobile if it covers the major portion of the trip cost, because automobile costs average $0.25 to $0.35/mi, including insurance.

4. At present, existing systems are not generating much income from nonpassenger sources. This is reflected in the incremental increase shown in information for total revenue per passenger mile compared with fare revenue per passenger mile. It appears that there are unaddressed opportunities in this area. For example, income from rental of nonoperating station areas has been a reliable source for PCS.

5. The passenger miles–per–train mile information is a gross figure that lumps peak and off-peak information together and is of little value as presented, because some of the reported services are more peak-period–oriented than others. In the case of PCS, the weekend and off-peak weekday ridership is growing at a faster rate than the peak-period ridership.

6. The peak–versus–off-peak ratio for a particular service also corrupts the reported data for passenger miles per train

mile. However, this factor is of value for indicating the worth of specific services and balancing train size with demand.

HOW DATA WERE USED

The information presented in Table 1 was used in obtaining approval for changes in Caltrain's fare structure. These changes, effective as of September 1, 1991, resulted in a fare increase averaging about 6 percent. It took 1 year from the date of the initial survey to implement the increase and 1½ years from the initial identification of the need for a fare adjustment. Ridership statistics for the first 2 months of the new fares indicate the goal of a 6 percent increase in income was obtained without an overall decrease in patronage.

The data for BART presented in Table 1 has been used by some to argue the relative roles of BART and Caltrain types of services. BART has many commuterrail service attributes, especially when considering its currently proposed line extensions. However, because of operational restrictions, such as inability to provide skip-stop service, it is less flexible than Caltrain in providing high-speed service. The statistics indicate that with equal fare policies, the two services would have comparable operating costs per passenger mile and a higher farebox recovery ratio for PCS.

The survey results will also be used as follows:

1. To develop the service under the expected new service provider. As of November 1991, it is expected that the local transit districts under the leadership of the previously formed Peninsula Corridor Joint Powers Board will take over PCS by mid-1992 with the service being provided by contract.
2. To identify possible changes in marketing strategy.
3. To identify possible efficiency and effectiveness improvement opportunities.

RESEARCH NEEDED

The reported data are a beginning in the identification of operating costs for providing commuter rail services. Further work is needed, for example, to match costs with the following:

1. Power source (diesel versus electric);
2. Labor costs (for both operations and management;
3. Contract versus owned services [including National Railroad Passenger Corp. (Amtrak) versus non-Amtrak contracted services];
4. Service levels (especially peak versus off-peak and weekend services); and
5. Fare policies (especially commuter and other reduced fares versus single-trip fares).

In addition, there is a need to define operating costs for commuter services to uniformly identify what costs should be charged to operations. The UMTA Section 15 reporting requirements go a long way in this regard, but not far enough. To exacerbate this, the Amtrak definition, as well as those used by several states, is not in agreement with the UMTA definition per Section 15.

REFERENCES

1. *Urban Public Transportation Glossary* (B. H. Gray, ed.). TRB, National Research Council, Washington, D.C., 1989.
2. *Compendium of National Urban Mass Transportation Statistics for 1986 Report Year*. Office of Grants Management, UMTA, U.S. Department of Transportation, April 1990.
3. *1990 Transit Operating and Financial Statistics*. American Public Transit Association, Washington, D.C., Nov. 1990.
4. Cal. Gov't Code § 14031.10.
5. Muni Workers Lead at $27.88 an Hour. *METRO Magazine*, Vol. 87, No. 3, May–June 1991.

Publication of this paper sponsored by Committee on Commuter Rail Transportation.

Feasibility Study for Providing Child Care at San Fernando Valley Commuter Rail Stations

CYNTHIA PANSING, PHYLLIS STEWART-PIRES, AND STUART ANDERSON

Child care is recognized by many transportation professionals as a key factor to consider when working to reduce traffic congestion. Fulfilling child-care responsibilities increases commute distance and trips for many working parents. It is also cited as one reason solo drivers are unable to carpool, vanpool, or use public transit. In order to increase transit ridership, a study was conducted for the Los Angeles County Transportation Commission to determine the feasibility of providing child-care facilities at two commuter rail stations in the San Fernando Valley area of Los Angeles. Each site offered opportunities for situating a facility at, or adjacent to, the rail center. Residents in both areas needed additional child-care facilities. To determine costs, a variety of area characteristics, including child-care demand and fees, were examined. Estimated capital and operating costs, weekly service fees, and administration options were identified. Total capital and operating costs were then applied to a pro forma budget designed to recoup costs through fees for the facility over an acceptable investment period. Overall, the study concluded that both sites should be pursued for child-care facilities.

To increase public transit services in Los Angeles County, the Los Angeles County Transportation Commission (LACTC) is developing a network of commuter rail lines. By October 1992 commuter rail service will begin operation throughout the San Fernando, Santa Clarita, and San Gabriel Valleys, and the southeastern portions of Los Angeles County. This new service will connect with existing service in Ventura, San Bernardino, and Orange counties. To improve patronage on two commuter rail lines that travel through the San Fernando Valley to downtown Los Angeles, LACTC conducted a preliminary study to assess the feasibility of providing child-care facilities at or adjacent to the proposed Chatsworth and Sylmar commuter rail stations in the San Fernando Valley.

BACKGROUND

The inextricable link between land use and transportation implies that solutions to traffic congestion cannot ignore issues associated with the location of various land uses—primarily jobs and housing, but also locations associated with the "other trips" category. Therefore, it is essential that transportation facilities and trip ends be brought closer together to achieve greater efficiency and enhance mobility. A prime example of this proposition is the proliferation of double-income households during the past decade. These households have resulted in an explosive growth need for child care that is considered a new contributor to travel demand during the morning and evening peak periods.

Providing new and varied forms of public transportation may encourage more people to leave their cars behind, but these new forms of transportation will not necessarily attract working parents if they cannot find high-quality, affordable child care near a transportation route. Commuting parents often state that child care is a primary reason for not carpooling, vanpooling, or using public transit (*1*). Providing child-care facilities at multimodal public transportation centers such as two proposed commuter rail stations in Los Angeles County might make public transportation a practical travel option for more commuters, especially women, who are limited by child-care requirements.

On the basis of a survey done in Santa Clara County, California, in 1988, it was found that parents using child care add an average of 3.1 mi to their trips from home to work each day (*2*). Another survey conducted by the California Department of Transportation (Caltrans) found that employees indicated an extra 4 mi was added to the one-way commute to work because of child care (*3*).

The time and distance added to a parent's commute because of child-care responsibilities highlight the importance of situating child-care facilities at public transportation centers. Such facilities, in reducing commute time and distance by providing parents with easy access to child care, will attract larger numbers of prospective riders to public transportation, as long as the child care is affordable, of good quality, and of ample supply to meet demand. This trilemma—affordability, quality, and supply—are the factors upon which the success of any child-care facility ultimately depends (*4*).

Precedent-setting examples of child-care projects at intermodal facilities attempting to address this important link between child care and transportation to resolve the child care trilemma are described in the following sections.

Tamien Station, San Jose

The local transit district will provide space on their property for a child care center at this intermodal facility located in a predominantly residential area of San Jose. The facility serves approximately 6,000 bus, light rail, and commuter patrons

C. Pansing, Los Angeles County Transportation Commission, 818 West Seventh Street, Los Angeles, Calif. 90017. P. Stewart-Pires, Burud & Associates, Inc., 56 East Holly Street, Suite 215, Pasadena, Calif. 91103. S. Anderson, Transportation Management Services, 959 East Walnut Street, Suite 200, Pasadena, Calif. 91106.

each day. A 4-month feasibility study and site analysis is in process.

The district intends to contract with a nonprofit agency to operate the facility. Although the district recognizes that parent fees will need to be subsidized to make the program affordable to the community using the transportation facility, no plans for an ongoing subsidy by the transportation district have been established.

City of San Diego Metropolitan Transit Agency

In February 1990, the Mt. Erie Trolley Day Care Center was opened in San Diego. For this project the San Diego Metropolitan Transit District made property available near the light rail line and was leased to a local developer for $1/year. The property was located adjacent to a housing project and the building was provided by the developer. The daily operations of the facility are the responsibility of the Mt. Erie Church. To enhance usage, the facility operates a child-care facility during the day and a senior citizen center in the evening.

DESCRIPTION OF COMMUTER RAIL STATION SITES

Each of the two proposed commuter rail station locations has unique demographic and environmental characteristics that provide both constraints and opportunities for accommodating prospective child care facilities at, or adjacent to, the sites.

Chatsworth is a rapidly growing residential area (45 percent growth during 1980–88) with light industrial development in a portion of the district. The median household income in 1987 was approximately $45,000 and nearly one-quarter of the total population is under the age of 17.

The proposed station site is an 11-acre lot that will eventually include approximately 140,000 ft^2 of retail space in addition to the commuter rail station. Most of the adjacent land uses are commercial in nature. Development at the site will be phased. To comply with the commuter rail schedule, the station will be built by October 1992 and the retail development will be constructed later. Because of the imminent operation of the commuter rail, a child-care facility will probably be incorporated into the retail phase of the development. On the basis of the projected ridership at the station and the surrounding community characteristics, including the existing supply of child care, the Chatsworth site would accommodate a facility that could serve approximately 90 children.

Sylmar is a predominantly lower income area and has low- to medium-density residential areas. The median household income in 1987 was approximately $26,000. Slightly less than one-third of the total population is under the age of 17. Like Chatsworth, the area is growing fairly rapidly.

Currently, the station site is 5.8 acres, which is a section of a 22-acre plot in which single-family homes are expected to be constructed. The residential development will be composed of a mixture of detached dwellings, townhomes, and condominiums. Joint development options for the site are also being explored. State assemblyman Richard Katz drafted legislation to allocate Petroleum Violation Escrow Account (PVEA) funds for partial construction costs of a child-care facility at or adjacent to this site. On the basis of a preliminary survey, staff at his office estimated that 75 children could be accommodated at this site. The small size of the station site and the parking requirements for commuter rail (approximately 300 spaces) may preclude putting a child-care facility on-site.

COMMUNITY SUPPLY AND DEMAND

The licensed child-care centers within a 1-mi radius of the two sites were contacted by telephone to determine their licensed capacity, ages of children served, vacancy rate, tuition, and hours of operation. At Chatsworth there appears to be a high demand for infant care, even though the cost of infant care averages $123/week. The average cost for preschool care in this area is $88.00/week; for school-age care, $45.50/week. At Sylmar it appears that there is a demand for child-care services in the area; however, most residents can not afford to pay the market rate.

SPACE REQUIREMENTS AND SITE PLANNING CONSIDERATIONS

On the basis of the total licensed capacity, California state licensing regulations for day-care centers require a minimum of 35 ft^2 of usable indoor activity space per child. Additional space must be included for toilet facilities, circulation space (such as hallways), storage, laundry, food preparation, and offices. In addition, napping space is required for children under 2 years old. Using a figure of 65 ft^2/child, these additional space requirements can be met. Because more space provides for a better quality center, 85 ft^2/child is recommended. The additional space provides for expanded activity space above the state minimum requirements. Similarly whereas licensing regulations require a minimum of 75 ft^2 of outdoor space per child, 100 ft^2 is recommended in order to provide higher-quality care.

Given the number of children projected at each site, the state would require a minimum of 5,850 (Chatsworth) and 4,875 (Sylmar) ft^2 of indoor space and 6,750 and 5,625 ft^2 of outdoor space. The recommended amount is 7,650 and 6,375 ft^2 for indoor space and 9,000 and 7,500 ft^2 for outdoor space, respectively.

In designing a child-care facility, the site should be examined so that the best locations for the building, parking, access, play yards, and walkways can be determined. The facility must accommodate different age groups: infants, toddlers, 2-year-olds, and older preschool-age children. Secondary activities such as eating, sleeping, and food preparation also occur within the facility and must be considered in design.

Building Entry

Because safe pedestrian access is required from the parking area to the center, the location for pick up and delivery of children should be as close as possible to the main entrance. It is preferred that curbside parking be provided so that parents and children do not cross traffic lanes. For the convenience of parents, the infant and toddler classrooms should be as close to the center's main entrance as possible. All primary use areas within the center must be accessible. Emergency vehicles need easy access to the center and the center should be marked so that it is easily identified by these vehicles. Provisions must also be made for access to and within the center for the physically disabled.

Parking

To ensure parking is near the center, spaces near the facility should be designated for child-care use only. Child-care facility staff parking would also need to be designated.

ZONING ISSUES AND SITE OPTIONS

Zoning

In the city of Los Angeles, child-care facilities are allowed in specific zones only and there is no limit on the number of children. Without a conditional use permit, child care is not permitted in industrial or manufacturing zones. However, it is possible to apply for a zoning variance to locate a child-care center in some unnamed zones.

Site Location

Chatsworth Option 1: Locate on Commuter Rail Property

On the basis of the preliminary plans for Chatsworth, there would be adequate space on the station property to accommodate a child-care center during Phase II of the plan. The main issues that should be considered regarding the specific location are whether there are any potential health and safety risks to the children in the program. There is a strip of light industry on the eastern side of lot, and this has raised some concerns about possible emissions. This light industry includes dog kennels and animal hospitals, a parking lot for waste control vehicles, a rebar loading facility, shipping and handling facilities, and some auto body refinishing shops. According to the local air-quality management district, the possible emissions of toxins from these types of facilities do not appear to warrant concerns. Before construction of the rail station facility, a local air regulation will require the level of volatile organic compounds emitted by auto refinishing facilities be reduced to a nonharmful level. An environmental impact report will substantiate whether any environmental concerns are justified.

Chatsworth Option 2: Locate on Proposed Adjacent Private Properly

The second preferred option is to locate the child-care facility at the center of the property immediately west of the proposed station. Because there is ample land at the station site to accommodate a child-care facility, this option should only be pursued if the environmental concerns at the station property are found to be substantive and significant. It might be possible to interest the owner of the property on the western side to include a child-care center in the development, however, if the owner is not willing to contribute the necessary property for the project, the cost to acquire the land could exceed the price of the facility.

Sylmar Option 1: Work with Residential Developer

The preferred location for the child-care facility is at the center of the proposed residential development that is next to the commuter rail station lot. The developer has a history of supporting the construction of child-care facilities. If guaranteed parking and a safe walking path to the facility are made available at this location, parents can still make one stop.

If this portion in the center of the development is not available, the next preferable site is close to one of the proposed access points of the housing development. The disadvantage of this site is that it requires a second stop by parents.

Sylmar Option 2: Locate on Station Property

A center to accommodate 75 children would require 10,500 to 13,900 ft^2 of property for suitable indoor and outdoor space. This option is an unlikely alternative because it would necessitate the displacement of some of the parking now being planned for the station. The addition of this type of facility on the property could, however, delay the rail project. One option that is being explored at the Tamien Station in San Jose is a child-care center above a parking structure. However, under Chapter 2-8 of the California State Building Code (Title 24), child-care facilities must be located on the first or second floor of a building, unless an exception has been granted by the state fire marshall. Additional restrictions regarding a sprinkler system and fire rating of the construction exist if the facility is to be located on the second floor.

Sylmar Option 3: Locate on Adjacent Property

Except for small pockets of commercial property, all other adjacent property within a two-block radius of the station would require a conditional use permit to enable a child-care facility to be placed there. Because of the severe shortage of child care, parents would be expected to use a facility located within a 1- to 2-mi radius of the rail station and use would depend on the fees, quality, ages of children served, and hours of the service. However, by increasing the distance from the station site, the center may in fact attract fewer commuter rail riders, even though a center at a distance would presumably reduce the number of miles that parents drive for child care. Thus, this option is not as ideal as a location next to the rail station, but in the event that it is the only alternative, it would help reduce commuting parents' trip distance to child care.

Developer Incentives

The city of Los Angeles has a series of developer incentives in place to encourage developers to build child-care centers. For example, a developer can qualify for a height and density bonus by including a child-care facility in a proposed development, and the development project as a whole can qualify for expedited processing through the regulatory and permitting process. Although these incentives are appealing to developers, those developers who consider building child-care centers often find these incentives insufficient to justify the expense of building the facility and frequently question the value a center will have as a tenant amenity. Although the perception may not necessarily be accurate, developers often feel that the relative appeal of the center to tenants will not be great, particularly if the developers pass on the cost of the facility to tenants in the form of higher lease rates. Because of the California State Building Code requirement restricting child-care centers to first and second floors, a center could replace lucrative ground-floor rental space.

COST PROJECTIONS

Given the shortage of child care in the Los Angeles area, there is enough demand for the size of centers being examined. Use, however, depends heavily on whether parents can afford the fees and the fees are determined by the quality of the program, the services offered, and the financial support the center receives from outside sources.

Construction Costs

Two cost scenarios were projected for each site. The first scenario meets minimum state requirements for indoor and outdoor square footage and assumes a construction cost of $65/ft^2. The second scenario meets quality standards in the child-care industry and assumes a construction cost of $100/ft^2. At the minimum level, Chatsworth would have 12,600 ft^2 and would cost approximately $500,000 with all site work, construction, landscaping, and consulting fees included. At the recommended level the facility would have 16,650 ft^2 and would cost approximately $960,000. For Sylmar, at the minimum level there would be 10,500 ft^2 at a cost of approximately $415,000. At the recommended level, the site would have 13,875 ft^2 and would cost approximately $800,000.

Additional Start-Up Costs

Additional start-up costs for a child-care center include indoor and outdoor furniture and equipment; office and staff workroom, lounge, and kitchen furniture and appliances; staff salaries before the center's opening; and program-curriculum design fees.

The costs do not vary by square footage, but they do vary by the capacity of the center. The total additional costs for Chatsworth would be $140,000 and for Sylmar, $120,000.

Ongoing Operation Expenses

Staff salaries are almost 70 percent of the total annual operating budget for a center. When benefits are included, the percentage rises to 80 percent. Therefore, the number of staff hired and the wages paid to staff are the critical elements in a center's budget. A lower staff-to-child ratio, higher staff salaries, and medical benefits promotes higher quality. These situations retain staff and reduce turnover, which also indicates a high-quality program. However, providing these salaries and benefits increases a center's operating budget and creates fees that are unaffordable to the parents who would like to use the center.

Two scenarios have been projected for each site. The first meets state minimum standards. The staff to child ratios are 1:4 for infants and 1:12 for preschoolers. Staff are paid $5 to $7/hr and have a minimal benefit plan. The second scenario meets accepted quality standards in the child-care industry. Staff-to-child ratios are at the high end of the National Association for the Education of Young Children standards. The ratios are 1:4 for infants, 1:6 for 2-year-olds, and 1:10 for 3- and 4-year-olds. staff are paid $6.50 to $8.50/hr and receive a more comprehensive benefit package.

For Chatsworth, annual operating costs would be $335,000 at the minimum level and $480,000 at the recommended level. For Sylmar, the annual operating costs would be $250,00 and $390,000, respectively.

The annual operating budgets for both sites are exclusive of lease costs and an operator's fee for managing the center. Depending on the type of operator used, there may be either a management fee or operator cost plus profit that would need to be incorporated into the annual operating budget.

Fees and Demand

If parent fees are expected to cover the annual operating costs of these centers, weekly fees would need to be set at the amounts presented in Table 1.

Market rate fees for center care at Chatsworth are $123 for infant care and $88 for preschool care. Therefore, it is anticipated that the parents who would use the Chatsworth center could afford the recommended average weekly parent fees. However, at Sylmar the majority of the licensed child-care centers are funded entirely by the state or have sliding fee scales. There is only one full-day program that charges $82.50/week at Sylmar, and this center has many vacancies. Therefore, it is assumed that the parents expected to use this center could not afford the weekly parent fees necessary to cover the operating expenses and would need the cost of care to be

TABLE 1 AVERAGE WEEKLY PARENT FEES (PER CHILD)

Site	Minimum		Recommended	
	Infant	Preschool	Infant	Preschool
Chatsworth	$85.00	$65.00	$126.00	$90.00
Sylmar	$80.00	$60.00	$124.00	$90.00

subsidized by some other source of funding such as government grants.

The projection of the total number of children of riders expected to use the commuter rail station child-care center is based on normative data compiled from employee child-care needs and assessments. A formula based on these survey data has been applied to the anticipated ridership population: 500 at Chatsworth and 300 at Sylmar. The total population figure has been reduced by the average percentage of employees who have children under 6 years old, the percentage of employees who are single parents or have a spouse who works, the percentage who are interested in using an on-site child-care center, and the percentage who could afford the cost of this care; it was then increased by the average number of children under 6 years old found in these households.

When this formula was applied to ridership assumptions, the expected usage of the center from rail riders is 45 children at Chatsworth and 27 children at Sylmar. It should be noted that this is the anticipated figure that would pay the full cost of the program. Usage of the child-care center would be greater if the center's fees were reduced (the fees could be set at a sliding scale according to income). If fees were not an issue, 73 children of riders at Chatsworth and 43 children at Sylmar would be expected to use the center.

Because of the shortage of child care in the area, there is anticipated additional usage of the center from community residents.

Start-Up Pro Forma Analysis

Chatsworth

The pro forma presented in Table 2 assumes that parent fees are set to cover the annual operating costs of the child-care center and the start-up funds are initially provided by the developer. It would take 21 to 24 years to recoup funds provided by the developer, depending on whether the minimum or recommended center characteristics are selected. In calculating the number of years it would take to recoup the funds, it was assumed that tuition increases at 4 percent per year, operating cost increases at 3% per year, the vacancy rate is 5 percent, and the permanent loan is at 10 percent interest over 20 to 25 years. For the minimum center, the weekly parent fees—$92/week for infant care and $72/week for preschool care—are under the market rate. However, the level of quality of the center could affect usage. For the recommended center the weekly parent fees—$135.50/week for infant care and $99.50/week for preschool care—are over the market rate by approximately $11.00/week for both infant and preschool care. These higher fees could outprice the service at the Chatsworth area. To keep fees closer to market rate for the recommended center, the start-up funds could be recovered over a longer period of time.

An alternative to this pro forma would be to contract with a for-profit provider to construct and operate the center. The provider would cover all start-up expenses and operate the center on an ongoing basis. The possibility of attracting a for-profit provider is greater at Chatsworth than Sylmar because of the difference in average household income level and greater profit potential.

Sylmar

The pro forma presented in Table 3 assumes that parent fees are set to cover the annual operating costs of the child-care center and that the majority of the construction costs are provided by the developer. It would take 10 to 18 years to recoup the funds provided by the developer, depending on whether the minimum or recommended center characteristics are selected. In calculating the number of years it would take to recoup the funds, it was assumed that tuition increases at 4 percent per year, operating cost increases at 3 percent per year, the vacancy rate is 5 percent, the PVEA funds reduce the start-up costs by $500,000, and the permanent loan is at 10 percent interest over 5 to 20 years. Because the majority of child-care centers in Sylmar are for low-income families with fees based on a sliding scale according to income, and the one center that charges $82.50/week has numerous vacancies, the weekly parent fees for both centers ($82.00 to $129.50/week for infant care and $62.00 to $95.50/week for preschool) are expected to outprice the service at the Sylmar site. The recommended center and subsequent higher fees will most likely be unaffordable for the community surrounding Sylmar, but the higher quality provided by this center could attract additional commuter usage.

ADMINISTRATION

Options for Operation

There are a variety of child-care operators that can be engaged to operate the proposed child-care facilities at the commuter rail stations. The type of organization selected will have an effect on the quality of the program, the locus of control, and

TABLE 2 CHATSWORTH PRO FORMA BUDGET (90-CHILD CAPACITY)

	Minimum	Recommended
Construction Costs	$499,385	$962,550
Equipment Costs	123,000	123,000
Personnel/Program Development	17,640	17,640
Total Start-up Costs	$640,025	$1,103,190
Number of Years to Recoup Funds	21 Years	24 Years

TABLE 3 SYLMAR PRO FORMA BUDGET (75-CHILD CAPACITY)

	Minimum	Recommended
Construction Costs	$416,155	$802,125
Equipment Costs	105,000	105,000
Personnel/Program Development	17,050	17,050
Total Start-up Costs	$538,205	$924,175
Less PVEA Funds	(500,000)	(500,000)
Balance	$ 38,205	$424,175
Number of Years to Recoup Funds	10 Years	18 Years

policy-making authority. The ability to set policy, such as program fees and hours of operation, will determine the population eventually served at the centers—whether transit riders or community residents.

Role of Sponsor

Several organizational models are used at employer-related child-care centers, and each offers a different approach to the control and responsibility issues. These distinctions have some similarities to the centers proposed because they are established for the purpose of serving a particular population rather than primarily being a community center.

The sponsor can simply rent space or property for a vendor to operate its own child-care program (little control, little responsibility). The sponsor can contract with a vendor to operate its own child-care program (little control, more responsibility). The sponsor can facilitate the spin-off of a separate organization (profit or nonprofit) to operate a center (more control, more responsibility). The sponsor may choose to operate the center directly (high control, high responsibility).

Because the sponsor wants to ensure that its goals are being met, the issue of control in achieving these goals is significant. For example, if the child-care facility is established in an effort to promote ridership on the commuter rail, the center must be operated in a manner that allows riders to use it. For example, it must be open during hours that permit rider use. It must meet the level of quality and provide the type of care (infant care, for example) required by this particular group of riders. If the program operator, rather than the sponsor, has the authority to set such stipulations, there is a risk that the basic goals will not be met.

Ideally, the sponsor provides policy direction (enrollment, tuition, services), defines quality assumptions, and participates in the proposed system for parent-consumer feedback. The sponsor typically designates a staff person to monitor the operation of the center (or the function can be assigned to a committee or task force). That individual or committee would be responsible for interacting with the operator, assuring contract compliance, and helping develop needed changes in policy or procedure.

Profit versus Nonprofit

Good-quality, well-operated child-care programs can be found among both for-profit and not-for-profit programs. Unfortunately, poor-quality programs are also found in both sectors. The advantage of some for-profit operations is the fact that they can absorb some of the start-up expenses. Non-profit programs [established as a qualified 501C(3) program] can more easily qualify for government and foundation grants, although some such financial resources are also available to for-profit providers.

An additional advantage of the nonprofit approach is that the funds (from parent fees) that would otherwise go toward profits of a for-profit operator can be put back into the center and this may allow parent fees to be lower than they would be otherwise. The disadvantage of this approach is that the quality of the board leadership varies with the individuals that are on it and can also fluctuate over time as the membership changes.

For-Profit Programs

For-profit operators range from small mom-and-pop operators that manage a single center to large child-care chains. Operators vary tremendously in capability, sophistication, quality, and style. Some for-profit providers have a cookie-cutter type of program and will not tailor a program to fit a given situation. Others will design the service in a highly individualized manner and be very responsive to the contracting organization.

The larger child-care chains have deep pockets and thus provide some level of protection from liability exposure, the greatest protection is the quality of the service provided. Child-care centers are required to carry liability insurance, but the best insurance is the avoidance of a problem. Thus, the quality of the care provided is the key consideration.

Options for Funding

Finding funding for child care, both start-up and ongoing expenses, is a difficult proposition. There may be some joint partnership opportunities available that could create unique avenues for funding. For example, other employers in the vicinity of the rail stations might be willing to consider participating in a consortium.

There are limited foundation funds and public funds currently available for child-care operations. For example, some large child-care operators will fund some or all of the start-up expenses of the center. Another way of funding start-up expenses is to lease the building space: Modular units and facilities built using regular construction can be leased. The initial outlay of funds can be avoided but the payment of the lease adds additional expense to the operating budget, which increases parent fees and could require greater outside financial support.

GENERAL CONSIDERATIONS

The following are issues that should be considered as part of any future facilities at Chatsworth and Sylmar rail stations.

Guaranteed Ride Home

The parent-employee must be assured that guaranteed rides home will be available in the event of an emergency call from the child-care center. Because the commuter trains operate during peak hours only, it is imperative to coordinate guaranteed-ride-home programs for those commuters who use centers on the transportation facilities. Because of the frequency with which young children become ill and must leave the child-care center, parents are unlikely to use a child-care program if they are not guaranteed access to the children during the day.

Proximity to Tracks

Playground walls, exits, emergency gathering points, and other design features will need to be developed to ensure maximum safety of the children participating in the program. These features need to be created during the design phase of any child-care center located near the transportation facilities that are near active tracks. Additionally, the flow of pedestrians between the center and the parking area must be planned to guarantee safe passage of children and parents.

Noise Level

Necessary design features can be created to protect the children from excessive exposure to noise. Placement of the child-care center and outdoor space should take into consideration the frequency with which trains are passing by and ways to reduce the noise.

Diesel Fumes

Caltrans also indicates that although there is not a great deal of research on the issue of diesel particulates and their impact on children, this has not been a prohibitive factor at other project sites. The risk increases with the length of time the trains are idle in the station. Caltrans has conducted research at their Trans-Bay Terminal project in San Francisco, which is an enclosed area through which many diesel-operated buses pass daily. Even with this amount of traffic and the enclosed space, Caltrans did not find the air quality to be unsafe. Caltrans also stated that with fresh air combining with the diesel particulates, the risk is even further reduced. In addition, this risk is no more than the risk of a child riding in a car on a busy freeway.

CONCLUSION

In summary, the child-care issue is an essential consideration in encouraging transit use. The provision of child care would enhance the appeal of transit and meet the excess demand for child care in each of the areas. However, a major factor to consider is that of holding down the costs and maintaining high-quality service. Operating costs can be covered by the fees, but some subsidization is required to obtain the land and to construct and equip the facilities.

REFERENCES

1. *1988 Commuter Survey: Final Report.* Commuter Transportation Services, Los Angeles, Calif., 1989.
2. J. Doyle, J. MacBrine, M. Marsh, and G. Stockdale. *Feasibility Study to Determine the Capacity of the Childcare Center to be Included as an Element of the Planned Alma Multi-Modal Terminal in San Jose.* California Department of Transportation, San Francisco, 1988.
3. J. MacBrine. State of California "Big Six" Survey: The Impact of Child Care on Employee Commute Behavior. Presented at the Calchapter American Planning Association Conference, San Jose, Calif., 1989.
4. G. Morgin. The Politics of Day Care: Who Pays for Child Care? *Day Care Journal*, Fall 1982, pp. 51–52.

Publication of this paper sponsored by Committee on Commuter Rail Transportation.

PART 3

Planning and Development

Transit Privatization in Denver: Experience in First Year

ROBERT L. PESKIN, SUBHASH R. MUNDLE, AND SCOTT D. BUHRER

The performance of the Denver Regional Transportation District (RTD) in its implementation of Colorado Senate Bill 164 of 1988 and Senate Bill 8 of 1990 and the resulting performance of the contractors selected by RTD to provide transit service in the region were reviewed. The bill required that RTD contract at least 20 percent of its service to qualified private businesses in negotiated contracts. Furthermore, the bill required that RTD contract with an independent certified public accounting firm for a neutral and unbiased performance audit. Over the 5-year term of the privatization contracts, RTD is projected to save more than $29 million (25 percent) on a fully allocated basis and nearly $16 million (15 percent) on an incremental basis over its in-house costs. And, for many measures of safety and quality of service, the contractors performed as well as or better than RTD. These positive findings must be tempered, however, by the consideration of significant front-end RTD costs resulting from contract administration and operational oversight; uncertain future contractor-proposed prices; lower performance by the contractors, in terms of some performance measures for some types of service; and poor initial performance by all of the contractors and continuing problems with one of the contractors. In addition, the results at the conclusion of the 3-year base term of the contracts (or after 4 or 5 years, if RTD exercises options with the current contractors) may vary from the findings contained herein, given the relatively short-term focus of this study.

This paper describes the performance of the Denver Regional Transportation District (RTD) in its implementation of the provisions of Colorado Revised Statutes 32-9-119.5, as amended—specifically the provisions of Senate Bill 164 of 1988 and Senate Bill 8 of 1990 (hereafter referred to as "SB 164" or "the bill")—and the resulting performance of the contractors selected by RTD to provide transit service in the region. SB 164 required that RTD contract at least 20 percent of its service to qualified private businesses in negotiated contracts. Furthermore, the bill required that RTD contract with an independent certified public accounting firm for a neutral and unbiased performance audit.

RTD contracted for service in four groups, each of which consisted of several smaller packages of individual routes. Contracts were of a 3-year initial term, with two 1-year options. Proposals were solicited for each package. This approach was intended to provide opportunities for smaller potential contractors to propose. From the proposals received, the following contractors were selected to provided privatized services: Mayflower Contract Services, Inc.; Laidlaw Transit, Inc.; and American Transit Corp.

R. L. Peskin, KPMG Peat Marwick, 8150 Leesburg Pike, Suite 800, Vienna, Va. 22182. S. R. Mundle, Mundle & Associates, Inc., 1700 Sansom Street, Suite 601, Philadelphia, Pa. 19103. S. D. Buhrer, City of Sunnyvale, 650 West Olive, Sunnyvale, Calif. 94086.

Revenue service for Groups I, II, III, and IV began on June 11, September 3, and December 10, 1989, and September 2, 1990, respectively. SB 164 called for RTD to submit its report to the general assembly by December 1, 1990. The period of evaluation in this study ended on June 30, 1990. The evaluation period included slightly more than a full year of Group I service, nearly 10 months of Group II service, and more than 6 months of Group III service. Group IV revenue had not yet commenced during the evaluation period. Thus, although 20.5 percent of RTD's service was contracted out (in terms of annualized revenue hours), only the performance of Groups I, II, and III (amounting to 19.4 percent of RTD's service, on an annualized basis) was evaluated in this paper.

This paper summarizes the following analyses conducted in the performance audit report (*1*):

- Comparison of RTD's cost had it operated the privatized routes with the costs it experienced when these routes were privatized;
- Contractors' actual costs and profitability;
- Safety and quality of service; and
- Contractors' compliance with the terms of their contracts.

The performance audit report also addressed, in considerable detail, RTD's management of transit privatization, including the process for solicitation of proposals, selection of contractors, and oversight during contractor start-up and revenue service.

COST COMPARISON OF RTD

Structure of Analyses

The cost comparison involved two alternative approaches to provide a realistic range in which the eventual fiscal results of privatization will most likely reside. This process was accomplished through the estimation of long-term, fully allocated costs and short-term, incremental (or "cash basis") costs.

Long-Term, Fully Allocated Cost Analysis

Fully allocated cost analyses implicitly assume that all costs were directly related to the level of service provided. The interpretation of long-term savings, as projected in a fully allocated cost analysis, must be made in the following context:

- RTD's administrative "Category 1" costs were influenced more by board and federal policy, organizational structure, and fixed capital plant than by service levels. Fully allocated cost analysis assumes that such costs were directly related to the quantity of service provided and thus projects pro rata savings. The likelihood of this occurring, particularly in the short term, is remote. Savings in administrative functions were dependent more on management initiatives and board policy than on service levels.

- Long-term financial forecasts, and the fully allocated cost projections on which they were based, were an economic concept that imply that RTD has the ability to modify the infrastructure that was assembled to operate the preprivatized service. This includes a large administrative staff and large discrete fixed assets (e.g., garages) that may be less efficiently deployed as a result of reducing directly operated service.

Long-term, fully allocated cost analyses may, therefore, provide an upper boundary of projected financial impacts.

Short-Term, Incremental Cost Analysis

Whereas the fully allocated cost approach was appropriate in determining long-term savings and awarding contracts, a more appropriate approach for estimating the short-term financial implications of privatization was the incremental costing methodology. The purpose of incremental cost analysis was to identify near-term "cash" effects of alternative management decisions, each resulting in alternative revenue and cost flows. This approach was addressed in the analysis in two ways:

- Indirect operating costs: The fully allocated analysis implied theoretical reduction in indirect costs of 20 percent, or proportionate to the quantity of service privatized. By contrast, the incremental analysis applied the actual and forecasted reductions in such costs identified in theRTD proposed amended 1990 and recommended 1991 budgets. These budgets reflect the actual cost reductions achieved by RTD before privatization.
- Depreciation costs: The incremental analysis does not address the sunk capital-related costs for depreciation decisions.

Short-term, incremental cost analyses may, therefore, provide a lower boundary of projected financial impacts.

Cost Allocation Model

RTD developed a state-of-the-art cost allocation model (*2,3*) that addressed the specific unit costs associated with the various types of service that RTD operated. This model was accomplished by distinguishing labor productivity and other unit cost factors for peak and off-peak service, various types of buses, and various RTD bus garages. It was thus possible to apply the model at the route level and to develop reasonable estimates of the cost for each group of service that was privatized.

For comparing of RTD's net in-house cost with RTD's net cost to privatize, the cost allocation model did not include the costs of "retained functions." These functions included various operations and administrative functions that RTD continued to provide regardless of whether it operated the routes to be privatized. Many of these functions represent systemwide responsibilities that could not be economically privatized or that RTD was specifically mandated to perform, including governance board, legal counsel, transit mall security, marketing, revenue collecting and reporting, grants management, janitorial services at terminals, planning, scheduling, street supervision, and maintenance of street facilities (e.g., bus stop signs, shelters, park-and-ride lots, and the 16th Street Transit Mall). These retained function costs represent $9.9 million, or approximately 9.8 percent of the adopted 1989 RTD operating budget.

In addition, the cost allocation model excluded from the analysis various capital project-related expenses, including construction claims management; interest, design, and construction administration; transitway technical analysis; construction quality and cost control; the Southwest Corridor Project; and the Rapid Transit Program. These excluded function costs represent $5.6 million, or 5.5 percent of the adopted 1989 RTD operating budget.

The cost allocation model classified costs according to the RTD chart of accounts, distinguishing between "Category 1" administrative costs and "Category 2" costs, largely associated with the transportation and maintenance functions. The costs of operating capital were allocated on the basis of fixed-asset depreciation costs. The 1989 and 1990 estimates were based on budgeted costs, adjusted for actual cost experience. The inflation rate for cost projections was based on a weighted average of inflation rates for labor and selected commodities prepared by the Colorado Bureau for Economic Forecasting.

The cost allocation model was based on the most recently available RTD internal cost data from just before the initiation of privatized service. These data included the operating budget from the current year, labor productivity data from the most recent 12-month period for bus operators and mechanics, and unit costs for parts and fuel. The model was initially validated and adjusted to replicate the 1989 budget, the year in which the privatization effort began.

Components of Cost of Privatization

RTD incurred the following fiscal impacts as a result of privatization:

- *Gross contractor cost to RTD*
  - *Invoice costs*. The contractors billed RTD on the basis of the quantity of service provided and a specified hourly rate of compensation. The proposals and the contracts included an annual increase in these rates (based on the contractors' assumption of the rate of inflation).
  - *Retained fare revenues*. Revenues retained by the contractors but previously received by RTD were retained for fare revenue. It was assumed that had RTD continued to receive the fares, the proposed prices would have been higher (by the amount of the fare revenues). Thus, these retained revenues were interpreted as a cost to RTD.
- *RTD labor costs charged to privatization*. RTD labor costs included both "one-time" costs associated with initiation of privatization (spread out over the 3-year base term of the

contracts) and estimated recurring costs for contract administration and operational oversight.

• *Consultant costs.* Consultant costs were a direct result of the provisions of SB 164 and included this performance audit, the development of the cost allocation model, and a study of privatization of RTD management.

• *RTD underutilized labor costs.* This amount included a projection of wages and fringe benefits for underutilized operators, mechanics, and service personnel resulting from the labor protection provisions of SB 164. These projected costs reflect adjustments for wage increases and more efficient use of bus operators permitted under the current union contract and for attrition.

• *RTD underutilized fixed-assets costs.* This included an allocation of the costs of underutilized RTD facilities. By choosing to lease buses, RTD efficiently managed the size of its bus fleet; in fact, RTD has been able to maintain its spare ratio (total number of active buses/peak buses − 1) at less than 20 percent.

• *Lease income.* Lease income included revenue generated by leasing RTD buses and the Longmont facility.

Results of Fully Allocated Cost Analysis

Table 1 summarizes the results of the comparison, on a fully allocated and an incremental basis, between RTD's cost had it operated the privatized routes and the costs it experienced when these routes were privatized. The fully allocated analysis financial impacts were computed as the difference between the following.

• Projected fiscal impacts had RTD directly operated privatized transit services (based on the results of the cost allocation model) of

—Category 1 (indirect) operating costs;
—Category 2 (direct) operating costs; and
—depreciation costs.

• Fiscal impacts resulting from RTD contracting transit services of

—gross contractor cost to RTD;
—lease income;
—RTD labor costs charged to privatization;
—consultant costs;
—underutilized labor costs; and
—Underutilized fixed-assets costs.

Two analyses were performed:

• *Cumulative costs over 5-year contract term.* This analysis addressed the cost savings that will result over the full 5-year term of the contracts. The analysis projected a 5-year savings resulting from privatization, on a fully allocated basis, of $29.347 million, or 24.5 percent of RTD's in-house cost.

• *Stable year costs.* This analysis focused on 1993, the last full year in which all the contracts will be in effect (assuming that RTD exercises the options). This analysis assumed that all transitional financial impacts associated with implementation of the privatization process (e.g., amortized nonrecurring RTD labor costs for contract administration and operational oversight, consultant costs, underutilized RTD labor, and bus lease income) diminish to zero. This analysis determined a stable year savings resulting from privatization, on a fully allocated basis, of $6.949 million, or 27.5 percent of RTD's in-house cost.

TABLE 1 RESULTS OF COST COMPARISON

Type of Analysis	Savings (Costs) of Privatization ($ Millions) 5-Year Cumulative	Stable year	Through 6/30/90
Fully Allocated	$29.3	$6.9	
	24.5%	27.5%	
Incremental	$15.9	$3.9	($1.0)
	14.9%	17.0%	

Results of Incremental Cost Analysis

The incremental fiscal impact of privatization was determined by summing favorable and unfavorable impacts.

• Favorable impacts resulting from privatization included

—*Lease income.* Lease income was the income resulting from leasing RTD buses and the Longmont facility; and

—*RTD cost reduction.* RTD realized actual cost reductions subsequent to privatization. These reductions included the actual and forecast reductions in Category 1 indirect costs (which were lower than the fully allocated projections). They also included reductions in Category 2 transportation and maintenance costs, adjusted for the adverse manpower utilization impacts of the labor protection provisions of SB 164 and efficiencies in manpower utilization achieved through recent changes in RTD's labor agreement.

• Unfavorable impacts resulting from privatization included

—Gross contractor cost to RTD;
—RTD labor costs charged to privatization; and
—Consultant costs.

The net savings resulting from privatization were computed as the difference between the above and modeled RTD in-house operating costs. These modeled costs included only Category 1 (indirect) and Category 2 (direct) operating costs. The incremental analysis did not address depreciation costs because these were sunk costs, expended before the privatization effort.

Three analyses were performed:

• *Cumulative costs over 5-year contract term.* Cumulative cost analysis addressed the cost savings that will result over the full 5-year term of the contracts. This analysis projected a 5-year net positive fiscal impact (or savings) resulting from privatization, on an incremental basis, of $15.859 million, or 14.85 percent of RTD's in-house cost.

• *Stable year costs.* This analysis focused on 1993, the last full year in which all the contracts will be in effect (assuming that RTD exercises the options). As in the fully allocated analysis, this analysis assumed that all transitional financial impacts were associated with implementation of the privatization process. This analysis projected a stable year net positive fiscal impact (or savings) resulting from privatization, on an incremental basis, of $3.852 million, or 16.96 percent of RTD's in-house cost.

- *Cash basis through June 30, 1990.* This analysis focused on cost and revenue experience during the period through June 30, 1990 (the most recent quarter for which financial results were available). The net cost of privatization included actual revenues and costs on a cash (not amortized) basis. This analysis estimated a net negative fiscal impact (or cost) of privatization of $1.009 million, on an incremental basis, through June 30, 1990.

ANALYSIS OF CONTRACTORS' ACTUAL COSTS AND PROFITABILITY

Actual cost information was obtained from each of the contractors. This information was reviewed for both completeness and reasonableness. To preserve the confidentiality of proprietary information, only the sum of the costs for all three contractors was published in the performance audit report.

This analysis determined that during the first year of operation, with start-up and leasehold improvement costs amortized over a 3-year period, the contractors lost approximately $217,000 out of total expenses of approximately $10.413 million (a loss of 2.1 percent). The contractors have indicated that they may have underestimated their projected costs for both start-up and revenue operations.

Despite initial operating losses, each contractor was an operational unit of larger corporations that have and may continue to fund relatively small local operating losses in individual operating units. Two of the contractors actively pursued other transit-related businesses in the Denver area. The privatized RTD services may effectively have been a "loss leader" that gave these contractors a foot in the door in the Denver marketplace. Without knowledge of the overall business strategy of each contractor, which is subject to change, the financial performance of individual operating units of larger businesses may not give any indication of the future price strategy of each contractor.

It is not possible to predict the economic conditions that influence contractor business and pricing strategies. If the current contractors are selected for future additional service, the effect of the start-up costs might be moderated, but all proposers will probably have higher hourly rates than those previously received by RTD. The reasons for the higher rates include

- *Initial operating losses.* As noted, the contractors lost money fulfilling the terms of their contracts, through the first year of privatized service.
- *Higher labor costs.* Some proposers may have anticipated the availability of RTD employees. Firms that were awarded contracts in Groups II and III found that few of these employees were available. The result may have been training costs that were higher than expected. Possible future unionization of contractor work forces may also result in higher labor costs for the contractors.
- *Higher fuel costs.* The significant increases in the costs of diesel fuel subsequent to summer 1990 were not anticipated by the contractors. RTD's contracts do not include any escalator for diesel fuel costs. Fuel costs, however, were a relatively small proportion of the contractors' actual costs (i.e., 6.2 percent). Further, the contractors have the opportunity to control these costs through bulk purchases or to use financial instruments to hedge against future price increases. This control could be accomplished by the large national firms, who have the opportunity to arrange fuel purchase contracts on a national level. Alternatively, the RTD contractors could pool their local fuel purchases.
- *Higher vehicle costs.* The Group I contractor has experienced increasing maintenance costs for its school-bus–type buses. RTD realized significant savings from proposals based on such less-expensive vehicles. These savings may not be repeated if future contractors propose only standard transit coaches.

SAFETY AND QUALITY OF SERVICE

The performance audit addressed the following measures: safety, on-time performance, maintenance reliability, and complaints. Because of inherent differences in operating conditions (e.g., density of street traffic) and passenger loadings, the comparison of safety and quality of service between RTD and the contractors distinguished between several types of bus services:

- *Local/limited radial routes.* These routes included local and limited routes operating largely on surface streets and either passing through or terminating in downtown Denver. Limited routes operated primarily during the peak periods over the same streets as local routes, but they made fewer stops.
- *Local/limited nonradial routes.* These routes included local and limited routes operating largely on surface streets but not entering downtown Denver. These routes, sometimes referred to as "crosstowns," generally encountered less-congested streets.
- *Express routes.* These routes included between suburban park-and-ride lots and either the Market Street Station or the Civic Center Station in downtown Denver.
- *Circulator routes.* Circulator routes had relatively low passenger volumes and operated between primarily residential areas and nearby commercial areas.

In addition, the "HandyRide" service for handicapped passengers was contracted out. Because of significant changes in the operation of this service (e.g., revised eligibility and expanded service), direct comparisons of safety and quality of service were not possible. This service represented only 1.6 percent of total vehicle hours.

Two other types of service were not specifically analyzed in this study.

- *Regional routes.* Regional routes occurred between outlying areas in the RTD service area. Because no qualified proposers submitted a price lower than RTD's in-house cost of providing the service, RTD did not contract for this type of service.

• *Mall shuttle.* Mall shuttle service operated with specialized low-floor vehicles on the 16th Street Transit Mall.

Safety

Figure 1 compares the performance of RTD and the contractors with regard to bodily-injury and property-damage accidents. The contractors' accident rates were lower than those of RTD for bodily-injury accidents but higher than those of RTD for property-damage accidents. This trend applied for all types of service. The contractors' property damage accident rates were much higher during the initial months of operation for local/limited radial routes and circulator routes.

On-Time Performance

Figure 2 compares the performance of RTD and the contractors with regard to on-time performance. The contractors' on-time performance was better than that of RTD for local/limited radial routes, approximately the same for local/limited nonradial and express routes, and slightly worse for circulator routes. Contractors were observed running late more often than RTD and running early less often than RTD.

Maintenance Reliability

Figure 3 compares the performance of RTD and the contractors with regard to maintenance reliability. During the quarter of April through June 1990, the contractors had a

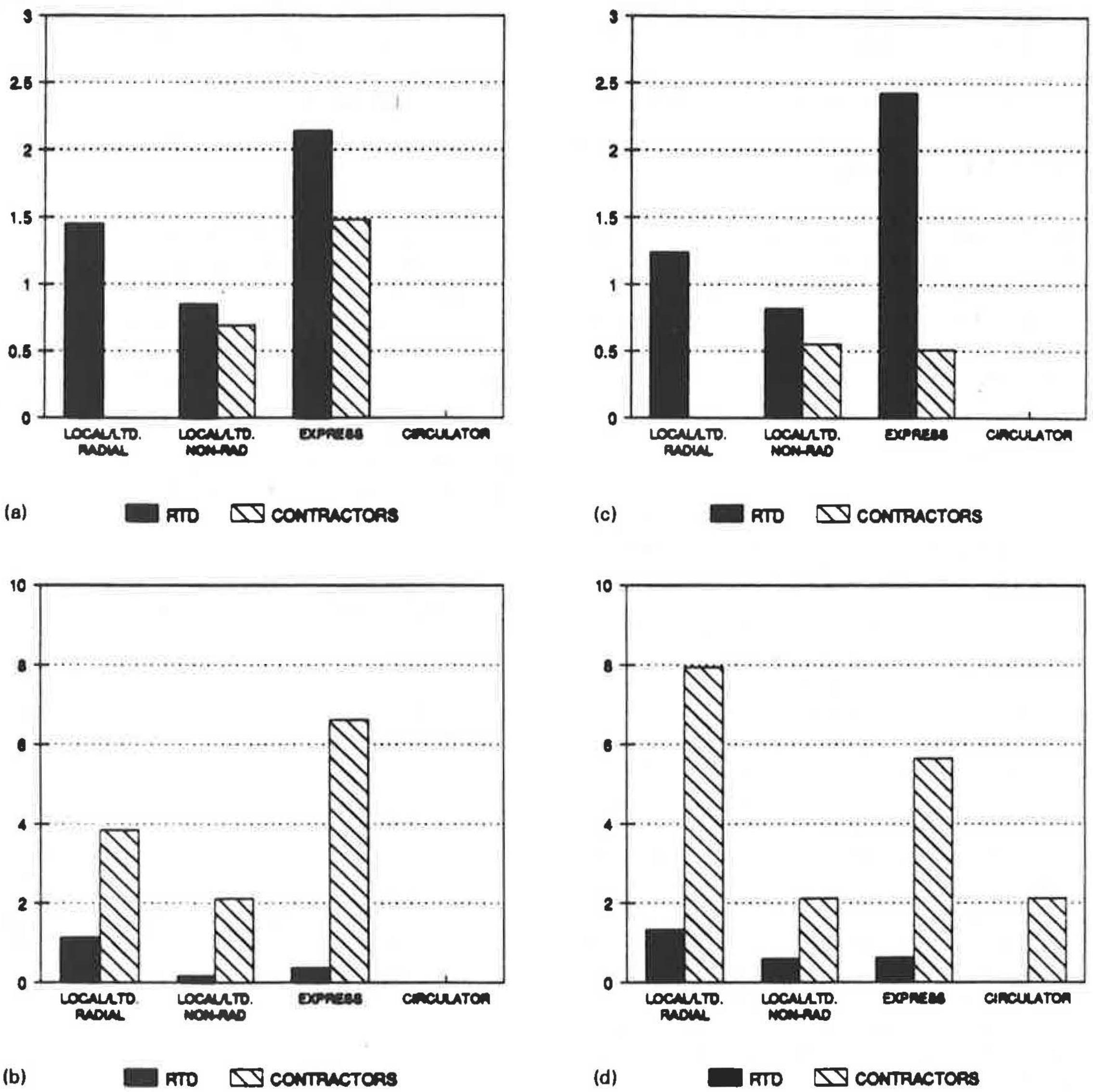


FIGURE 1 Comparison of RTD and contractor performance for bodily-injury accidents per 100,000 passengers *(a)* April through June 1990 and *(c)* June 1989 through June 1990 and for property-damage accidents per 100,000 vehicle-mi *(b)* April through June 1990 and *(d)* June 1989 through June 1990.

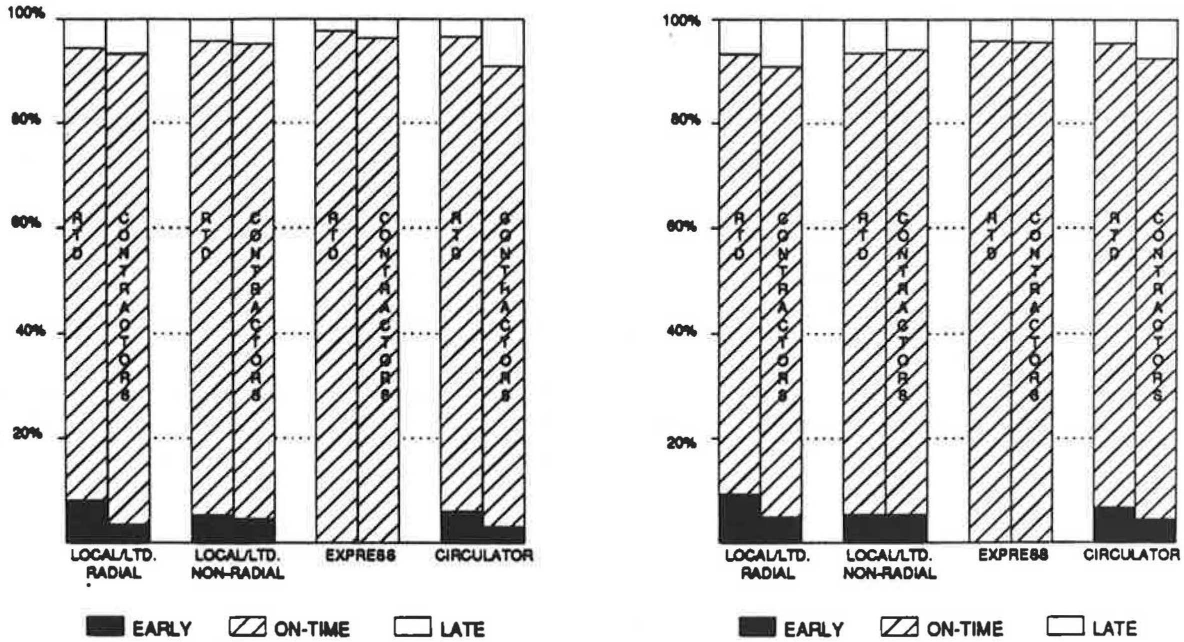


FIGURE 2 Comparison of RTD and contractors for on-time performance April through June 1990 (*left*) and June 1989 through June 1990 (*right*).

worse rate of miles between roadcalls than RTD for all types of service. The contractors' miles between roadcalls declined over the total analysis period. This decline can be partially explained by the new vehicles operated by the Group I contractor, which experienced fewer in-service maintenance problems during the initial months of operation.

Complaints

Figures 4 through 6 compare the performance of RTD and the contractors with regard to complaints concerning operator performance, maintenance, and on-time performance.

- *Operator performance.* Contractor performance was approximately the same as that of RTD for local/limited radial and express routes. Contractor performance was much better than that of RTD for circulator routes.
- *Maintenance.* During the quarter of April through June 1990, the contractors performed slightly better than RTD for express routes and worse than RTD for circulator routes. In the total analysis period through June 1990, the contractors performed worse than RTD for express routes but significantly better than RTD on circulator routes.
- *On-time performance.* The "early" complaint rate of contractors was similar to that of RTD for local/limited radial and radial and express routes. The early complaint rate of contractors was higher than that of RTD for circulator routes in the quarter of April through June 1990 but lower in the total analysis period through June 1990. The contractors had a higher "late" complaint rate for local/limited radial and express routes but a significantly lower rate for circulator routes. The contractors had a higher "no-show" complaint rate for local/limited radial and express routes but a significantly lower rate for circulator routes.

Complaint data have significant limitations. Solely on the basis of the volume of complaints received at the RTD Telephone Information Center, the data reflect none of the follow-up routinely given complaints by both RTD and the contractors. The validity of each complaint was not researched before it entered the data base. Furthermore, none of the complaints received directly by the contractors (at their local offices) was included. The extent to which the complaint findings differ from the maintenance roadcall and observed on-time performance data can be explained partially by these limitations.

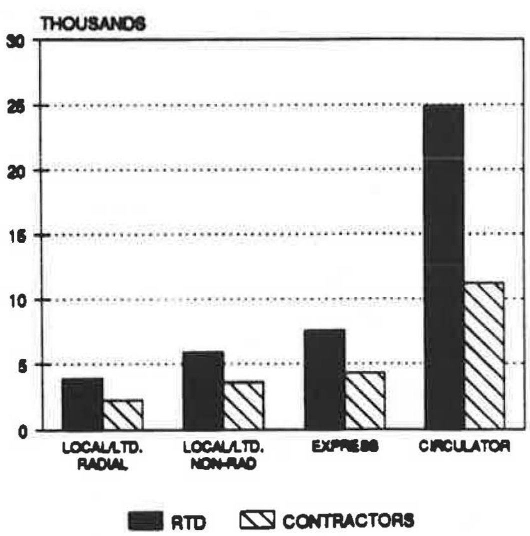


FIGURE 3 Comparison of RTD and contractors for maintenance reliability by type of service (in miles and between roadcalls, April through June 1990).

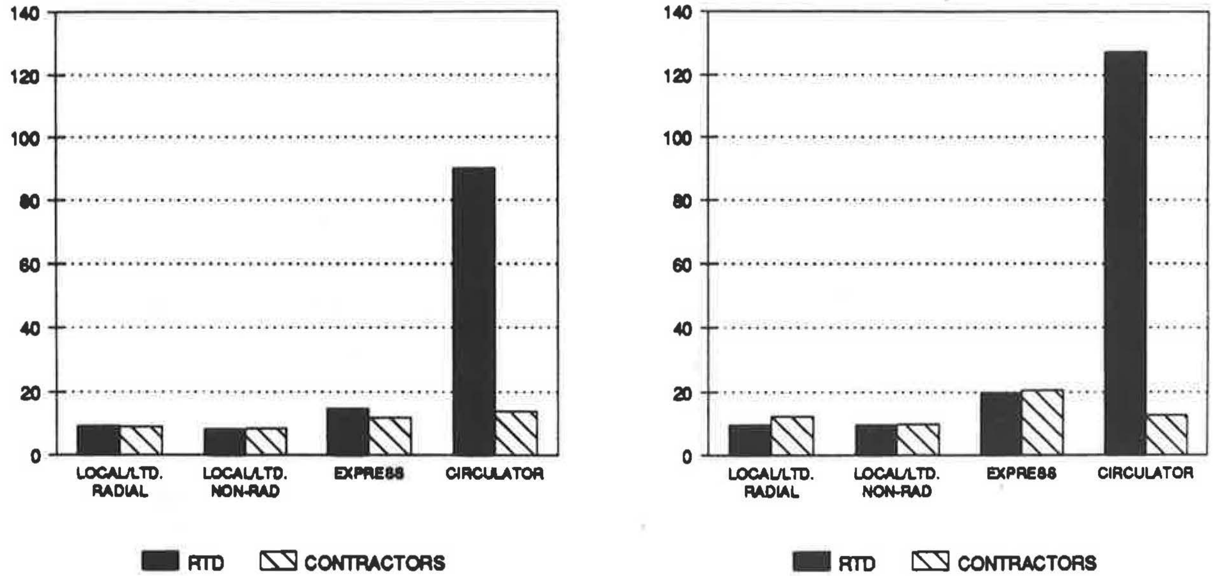


FIGURE 4 Comparison of RTD and contractors for operator performance complaints per 100,000 passengers April through June 1990 (*left*) and June 1989 through June 1990 (*right*).

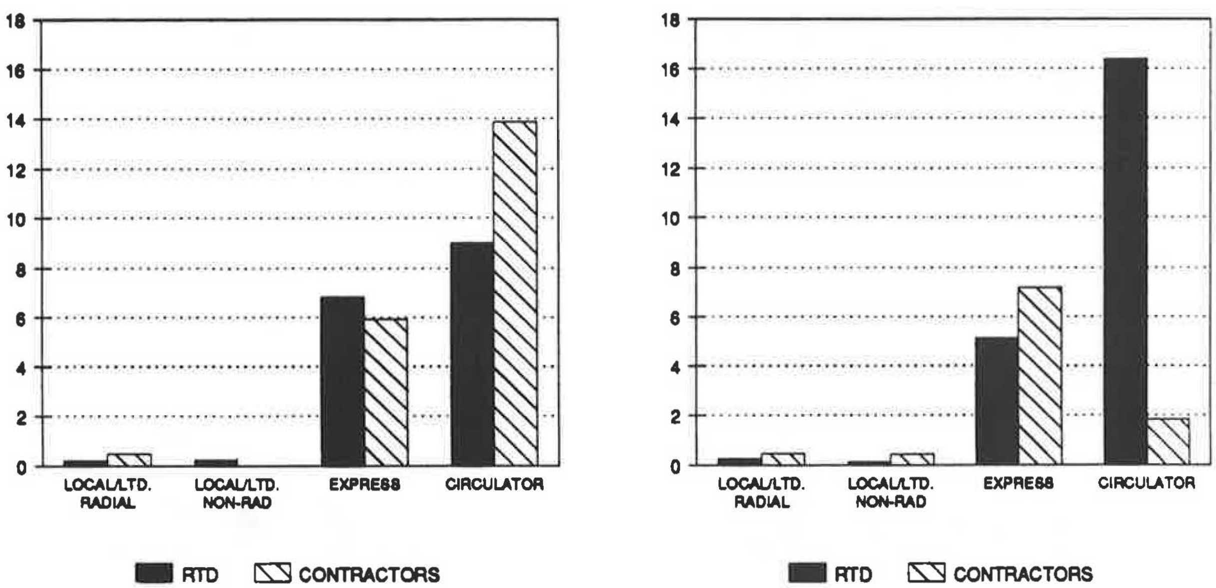


FIGURE 5 Comparison of RTD and contractors for maintenance complaints per 100,000 passengers April through June 1990 (*left*) and June 1989 through June 1990 (*right*).

CONTRACTORS' COMPLIANCE WITH CONTRACT TERMS

RTD applied two quantitative approaches to measure overall contractor compliance:

• *Service delivery*. RTD addressed service delivery through two gross measures: revenue hours and vehicle miles. In the total analysis period through June 1990, the contractors delivered in excess of 99.8 percent of scheduled revenue hours. This measure was based on daily service provision reports by the contractor and verified by electronic farebox data (for two contractors) and observation by RTD traffic checkers and street supervisors.

• *Liquidated damages*. The contracts included a provision for RTD to assess liquidated damages in those cases of observed lack of compliance by the contractors. As summarized in Table 2, through June 30, 1990, a total of 495 liquidated damage incidents were initiated by RTD, of which 288 were eventually assessed. The most frequently assessed liquidated damages resulted from contractors' being observed running early and late, missed trips, nonfunctioning wheelchair lifts, and displaying the improper destination sign. Overall, there was a broad range in the compliance among the three contractors.

RTD's experience went beyond the quantitative descriptions described above, however. From RTD management's

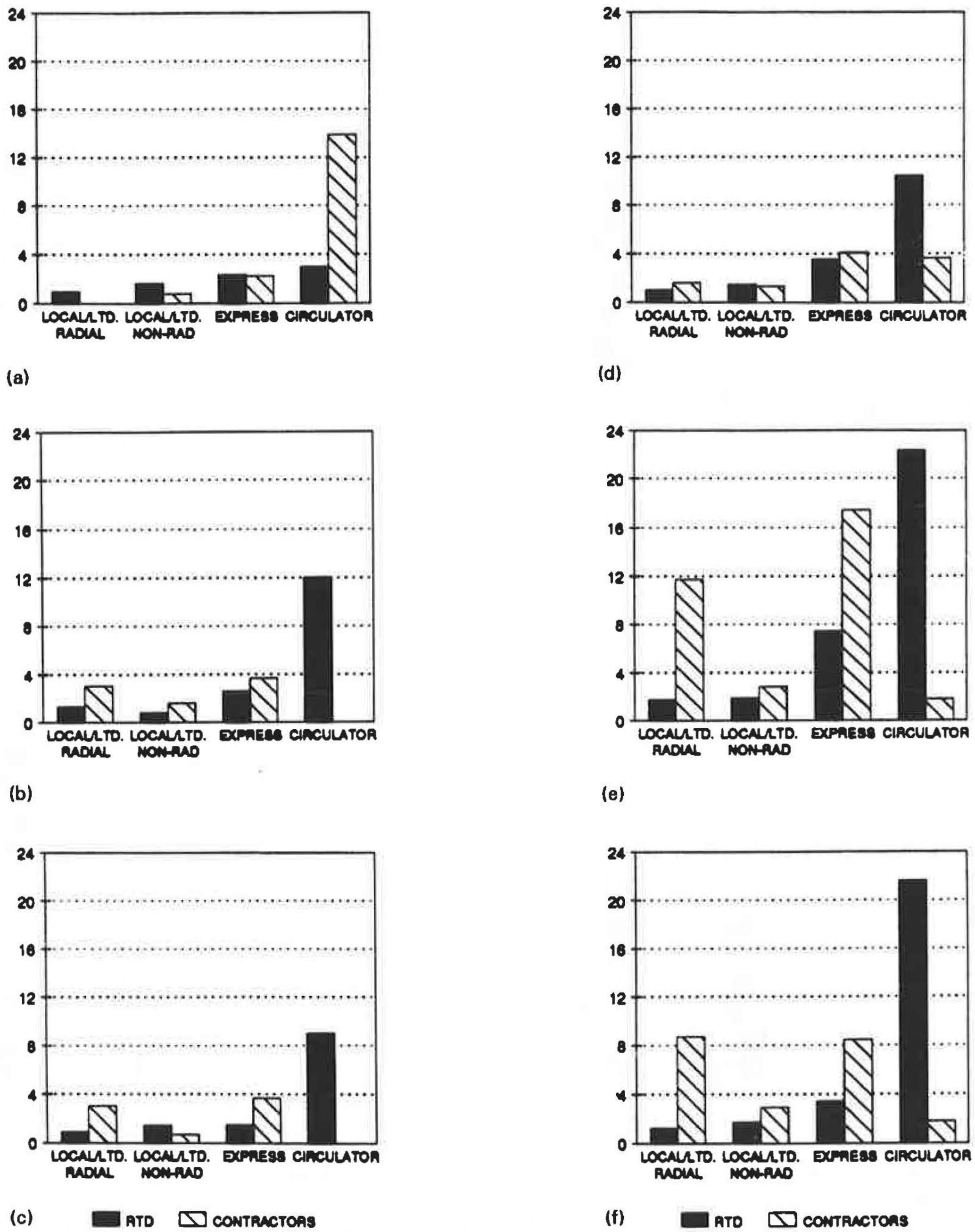


FIGURE 6 Comparison of RTD and contractors for on-time performance April through June 1990 for (*a*) early complaints, (*b*) late complaints, and (*c*) no-show complaints; and June 1989 through June 1990 for (*d*) early complaints, (*e*) late complaints, and (*f*) no-show complaints.

perspective, one contractor had relatively few problems and has generally been receptive to recommendations for improvement from RTD management. Another contractor, after experiencing significant problems during start-up and initial revenue service, applied increased corporate and local management oversight to resolve its operational problems and eventually operated with only minor, routine problems. Concerns were raised about whether the remaining contractor had an adequate level of management and supervision.

RTD transmitted cure notices to one of the contractors in the initial weeks of its revenue service. These notices addressed the contractor's failure to maintain its leased buses per the terms of the lease and to meet RTD contract standards for the quality of service provided (e.g., failure to provide service and on-time performance). The cure notices were issued after the assessment of a large number of liquidated damages and extensive discussion with the contractor's on-site manager and corporate management. The contractor quickly responded to the cure notices, which have since been closed.

The following contractors' incurred costs were either related to complying with their contracts or a result of being observed in noncompliance.

- *Start-up and leasehold improvements.* Nonrecurring start-up and leasehold improvement costs amounted to $1.6 mil-

TABLE 2 LIQUIDATED DAMAGES JUNE 1989 THROUGH JUNE 1990

	Initiated	Assessed
Incident Type		
Failure to Provide Service	0	0
Missed Trip/1 Min Early/30 Min Late	170	111
Between 5 Min and 30 Min Late	156	77
Route Deviation	27	14
Non-Assigned Required Personnel	0	0
Non-Functioning Wheelchair Lift	65	48
Unclean Vehicle/Unrepaired Damage	2	1
Non-Functioning Heating/Cooling System	12	4
Driver Not In Presentable Uniform	4	3
Improper Vehicle Maintenance	12	9
Improper Destination Sign	47	21
Failure to Remove RTD Logo When Providing Other Than RTD-Contracted Service	0	0
Total	495	288
Total Incidents per 100,000 Vehicle Miles	10.54	5.44
Total Value of Liquidated Damages		
June-September 1989		$3,520
October-December 1989		$16,475
January-March 1990		$5,850
April-June 1990		$4,000
Total		$29,845

lion, or 2.4 percent of the 5-year total contract price. Amortization of these costs over the initial 3-year term of the contracts brought them to $418,000 or 4.1 percent of total actual costs through June 30, 1990. These costs were the result of the following:

—Training: Training included costs to hire and train bus operators, mechanics, cleaners, supervisors, and instructors.

—Buses: Contractors operating their own vehicles were required to paint the buses to RTD standards and install wheelchair lifts, emergency exits, and destination signs to meet RTD specifications.

—Facility preparation: The contractors acquired operating facilities that had to be converted for transit use. These preparations included constructing office space; installing shop equipment, ventilation, and lighting; and paving storage areas. One contractor leased RTD's Longmont facility, thereby limiting this expense somewhat.

- *Liquidated damages.* Assessed liquidated damages resulted in a total cost of $27,625 to the contractors, representing less than 0.3 percent of the contractors' total actual costs.

CONCLUSIONS

RTD's privatization effort demonstrated that it is possible to reduce its net cost by contracting for transit services from private providers. Over the 5-year term of the privatization contracts, RTD is projected to save more than $29 million (25 percent) on a fully allocated basis and nearly $16 million (15 percent) on an incremental basis over its in-house costs. In stable years, after various privatization initiation costs have been fully amortized, the annual savings were projected to be as high as 28 percent on a fully allocated basis and 17 percent on an incremental basis. For many measures of safety and quality of service, the contractors performed as well as or better than RTD.

These positive findings must be tempered, however, by the consideration of

- Significant front-end RTD costs resulting from contract administration and operational oversight;
- The uncertainty of future contractor proposed prices and, hence, RTD cost savings given higher-than-expected contractor start-up costs and initial operating losses;
- Lower performance by the contractors in terms of some performance measures, for some types of service; and
- Poor initial performance by all of the contractors and continuing problems with one of the contractors.

The results at the conclusion of the 3-year base term of the contracts (or after 4 or 5 years, if RTD exercises options with the current contractors) may vary from the findings contained herein, given the relatively short-term focus of this study.

RTD faced the challenge of maintaining a balance between providing the contractors the opportunity to run their own businesses effectively and profitably and protecting the public's interest through preserving safe and reliable service and protecting RTD assets leased to the contractors. While it recognized the potential advantages of the profit motive and competition in controlling the proposed price, RTD also made provision for controls to ensure that all services contracted for were actually provided and were consistent with RTD's own safety and service quality standards. RTD has attempted to control these factors through the following procedures.

- *Attention to the "business" side of privatization.* Attending to the business side included preparing requests for proposals, selecting contractors, and providing program oversight. RTD structured a procurement process that was intended to protect the public's interest, in terms of safe and reliable service, and provided opportunities for qualified local and small businesses.
- *Contractor selection.* Contractors were evaluated and judged qualified on the basis of previous operating experience, adequate understanding of the Denver situation and approach for organizing the implementation of privatized service, and sufficient financial capacity.
- *Performance incentives.* Incentives were in the form of retention of 100 percent of fare revenues collected.
- *Performance penalties.* Penalties were in the form of liquidated damages for noncompliance of specific contract articles related to service provision and safety and service quality.

Routine observation by RTD street supervisors, spot inspections of vehicles and facilities, and periodic meetings with the contractors ensured that service safety and quality were measured, that problems were identified, and that resolution of problems could be initiated. The dedication of both contracts and operations department project managers helped ensure that the appropriate level of attention was paid to the privatization effort.

A concern with RTD's management approach, identified by the contractors and others, is the temptation for RTD to impose its own expectations about how the contractors should manage their businesses. Although RTD was properly concerned about the adequacy of training and the level of street supervision during the initial months of privatization, the initial mobilization problems faced by the contractors have largely been overcome.

The incentive-penalty system used by RTD had several weaknesses:

- *Limited financial impact.* The dollar amount of the incentives and penalties were too small to be of significant importance to the contractors. Incentives from retained fare revenues were difficult to determine, because the effect of the recent fare restructuring probably overshadowed any passenger response to quality of service. In all likelihood, such incentives would have been small because, in the total analysis period, retained fare revenues equaled less than 17 percent of total contractor costs. Penalties resulting from liquidated damages amounted to less than 0.3 percent of contractor costs.
- *Limited opportunity for contractor control.* The incentives to the contractors for good-quality service were based on fare revenues received. Unfortunately, the contractors did not have the ability to directly control two important aspects of fare revenue. The overall fare structure was imposed by RTD. Although the recent fare restructuring actually benefitted the contractors, the revenue increase probably had little to do with the quality of service they provided. The other aspect affecting fare revenue was ridership. Prevailing regional economic conditions, as well as route-specific changes (e.g., expansion or elimination of major employers and changes in traffic congestion) could have had as much or greater influences on ridership than any change in service quality.
- *Inconsistent observations.* Liquidated damages were imposed by RTD on the basis of observations from a variety of sources. These include observations by street supervisors, maintenance inspections of buses, and passenger complaints. There was no assurance that the occurrence of these observations was uniform or consistent. Street supervision, for example, was deployed based on day-to-day and hour-to-hour operational considerations rather than on any attempt to observe all service. By contrast, measurement of on-time performance by traffic checkers was an example of unbiased performance measurement. The number of observations was in approximately the same proportion as the number of revenue hours operated by the contractors. Thus, the on-time performance of each contractor had the same likelihood of being observed.

ACKNOWLEDGMENT

The study described in this paper was performed by KPMG Peat Marwick, in association with Mundle & Associates, Inc., under contract to the Denver RTD.

REFERENCES

1. KPMG Peat Marwick and Mundle & Associates, Inc. *Performance Audit of Privatization of RTD Services.* Revised Final Report. Regional Transportation District, Denver, Colo., Dec. 24, 1991.
2. KPMG Peat Marwick and Mundle & Associates, Inc. *Development of Fully-Allocated Cost Model in Compliance with UMTA Guidelines.* Working Paper 2 (Revision 3). Regional Transportation District, Denver, Colo., Aug. 1989.
3. KPMG Peat Marwick and Mundle & Associates, Inc. *Modification of Fully-Allocated Cost Model to Address Retained Functions.* Working Paper 3 (Revision 2). Regional Transportation District, Denver, Colo., June 1989.

Although all factual information was provided by RTD and its contractors, any opinions and conclusions expressed in this paper are solely those of the authors.

Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Reverse Commuting: Prospects for Job Accessibility and Energy Conservation

Z. ANDREW FARKAS

The problems of job accessibility and energy consumption associated with metropolitan decentralization have not been solved by conventional mass transit. The potential exists for new public transportation options that increase accessibility to suburban jobs and use energy more efficiently. The factors constraining low-wage urban labor from commuting to suburban jobs and the demand for reverse commute services are examined, and public transportation options that would increase accessibility and conserve energy are identified. The focus is on the Baltimore metropolitan area. The suburban activity centers in the metropolitan area are relatively inaccessible by transit from many areas of Baltimore City. Travel times for reverse commute transit are often greater than those for suburb-to-city transit. Low-wage urban labor uses transit, automobile, and paratransit modes for commuting in the city but desires higher wages and automobiles or higher-quality public transportation for commuting to the suburbs. Additional paratransit options could increase accessibility and vehicle loads, resulting in a large saving of energy. Creating busways and high-occupancy-vehicle lanes that can be used cost-effectively for the reverse commute should be considered. Government and private-sector employers should aggressively market ridesharing to the urban labor force and pay financial incentives to attract labor to suburban jobs and to paratransit services.

The continued decentralization of metropolitan areas has reduced the accessibility of low-wage inner-city residents to employment and has promoted increased energy consumption for commuting to work. It is a worthy societal objective to increase the accessibility of labor to suburban employment opportunities. Public transportation officials must market services that are in demand and that promote other societal objectives, such as increased energy conservation and improved air quality.

Cervero noted that the suburbanization of work places aggravates the high jobless among inner-city minorities (*1*). Inadequate public transportation for a reverse commute and the high cost of housing in suburban areas deter inner-city labor from reaching jobs at these activity centers. Ottensman found that Milwaukee districts with the poorest people and the lowest-quality housing experienced the greatest deterioration in accessibility to employment opportunities because of suburbanization (*2*).

A National League of Cities report found that the growth and concentration of poverty in urban areas has been caused by the relocation of jobs to the suburbs and the decreasing demand for unskilled workers (*3*). The percentage of people in Baltimore living in extremely poor neighborhoods, primarily blacks and Hispanics, grew from 28 to 34 percent between 1970 and 1980. These neighborhoods have been transformed into expanding ghettos that are far from job opportunities.

Notess found that a typical black worker in Buffalo, New York, could reach more than 25 percent more jobs by a half-hour bus trip in 1952 than in 1968 because of the movement of jobs to suburban locations (*4*). The average journey to work from the inner city by automobile took 12 min in 1968, whereas the average travel time by bus was 30 min.

A National Urban Coalition study found that transit systems were oriented toward collecting suburban residents for line-haul service to the central business district (CBD) (*5*). Reverse commuters often found collection points in the city to be inconvenient and the suburban destinations to be considerable distances from job sites. Bigler and Keith reported that the time and cost of reverse commuting by transit were almost prohibitive to the urban poor (*6*).

The dispersed job locations of suburban areas also cause greater energy consumption during the journey to work relative to higher-density areas. Anderson, using 1986 data from UMTA [now the Federal Transit Administration (FTA)], found that ridership, a function of density, was a significant influence on energy use by urban public transportation modes (*7*). He compared the energy use per passenger mile of eight modes. Energy use consisted of energy for propelling and heating or cooling the vehicle and energy for constructing the vehicle and the way. The modes that were found to use the least total energy per passenger mile were the vanpool and personal rail transit. The modes that used the most were dial-a-bus and light rail.

In response to the concern over energy use and public transportation policy in the 1970s, Lutin analyzed energy consumption by various modes for work trips in New Jersey (*8*). He calculated the number of work trips by automobile and transit (bus and rail), energy consumption per vehicle mile, and vehicle occupancy. Because of the overwhelming number of trips by automobile and existing work trip patterns, relatively minor increases in automobile occupancy yielded greater savings in energy than substantial diversions of automobile users to transit.

Lutin concluded that increased bus service in low-density suburbs will most likely result in inefficient use of energy because transit ridership and population density are positively related. Pikarsky noted that low-density suburbs have not been served by conventional mass transit in an energy-efficient manner (*9*). Cox stated that because transit often cannot be used effectively in suburban areas, its reliability is limited during an energy emergency (*10*). However, for urban and suburban areas, mass transit has been the traditional tool for promoting energy conservation in the work commute.

Center for Transportation Studies, Morgan State University, Baltimore, Md. 21239.

RESEARCH HYPOTHESES, OBJECTIVES, AND METHOD

It is apparent from the literature that problems with job accessibility and energy consumption associated with metropolitan decentralization have not been solved by conventional mass transit. Low-wage urban labor, not unlike other income groups, demands frequent, high-quality, and speedy transportation services for commuting to suburban employment. Suburban activity centers are relatively inaccessible from many areas of the city, but the potential exists for new public transportation options that increase accessibility to suburban jobs and use energy more efficiently.

The objectives in this paper are to examine the transportation factors constraining low-wage urban labor from commuting to jobs at suburban activity centers, examine the determinants of demand for reverse commute services, and identify those public transportation options that would increase accessibility and conserve energy. The focus is on conditions within the Baltimore metropolitan area and conditions similar to those in other large metropolitan areas.

The research methodology includes review of local studies and reports on regional commuting and economic trends, application of a survey to low-wage unemployed urban labor, statistical analysis of survey data, and analysis of secondary data on work trips.

The analyses concentrate on areas of Baltimore City and on suburban activity centers as designated by the Baltimore Regional Council of Governments (BRCOG): Baltimore-Washington International Airport (BWI), Columbia/Route 1, Hunt Valley, Owings Mills, Towson, and White Marsh (Figure 1). All of the suburban activity centers are major nodes of industrial, commercial, and residential growth. They have been selected as planned growth areas that would receive the bulk of development in their counties. All except Towson are outside the circumferential highway, I-695, along major corridors radiating from Baltimore City. These centers have had abundant vacant land, which in a robust economy has contributed to rapid rates of growth.

METROPOLITAN AREA EMPLOYMENT AND COMMUTING

Urban decentralization has involved jobs at all skill levels and middle- to upper-income households; low-income, transit-pendent households have remained in the inner city. Firms in many suburban locations have difficulty attracting low-wage and low-skilled labor. As of May 1991, the unemployment rate in the city of Baltimore was 9.5 percent; for the metropolitan area as a whole, the unemployment rate was 6.6 percent (*11*). Howard County, in the corridor between Baltimore and Washington, D.C., and the fastest growing county in the metropolitan area, had an unemployment rate of 4.1 percent. In 1988 the metropolitan area had average annual unemployment rates of 3.2 percent for whites and 12.2 percent for blacks (*12*).

According to employment estimates by BRCOG, between 1980 and 1985 the metropolitan area's labor force and employment grew by 2 and 7 percent, respectively (*13*). During the same period, Baltimore City's labor force declined from 360,000 to 340,000, a decrease of 6 percent. The number of jobs in Baltimore City declined from 458,600 to 424,400, a decrease of 8 percent.

In the six suburban activity centers selected for study [Regional Planning Districts (RPDs) 201, 202, 306, 309, 314, 315, 317, 605, 606, and 607], the labor force grew from 128,650 to 146,180 between 1980 and 1985, an increase of 14 percent (*13*). Employment increased 25 percent, from 171,550 to 214,370. The activity centers contributed to 81 percent of the metropolitan area's labor force growth and 55 percent of the metropolitan area's employment growth between 1980 and 1985.

The contrast between city and suburban counties is also apparent from the differences for work-trip destinations and choices of mode to work. During the 1980s several changes occurred in the commuting patterns, choices of travel mode to work, and vehicle ownership, according a comparison between BRCOG's 1988 household travel survey and 1980 census data (*14*). Each jurisdiction in the metropolitan area had an increase in the percentage of internal commuter trips between 1980 and 1988; more trips originated and ended in the jurisdiction of residence. The percentage of commuter trips originating in Baltimore City and ending in other jurisdictions, for example, fell from 30 to 24 percent of all commuter trips originating in the city.

The suburban counties attracted relatively fewer commuter trips by Baltimore City residents, despite a city employment base that continued to erode. Apparently, Baltimore City residents have become less willing or less able to commute to suburban jobs.

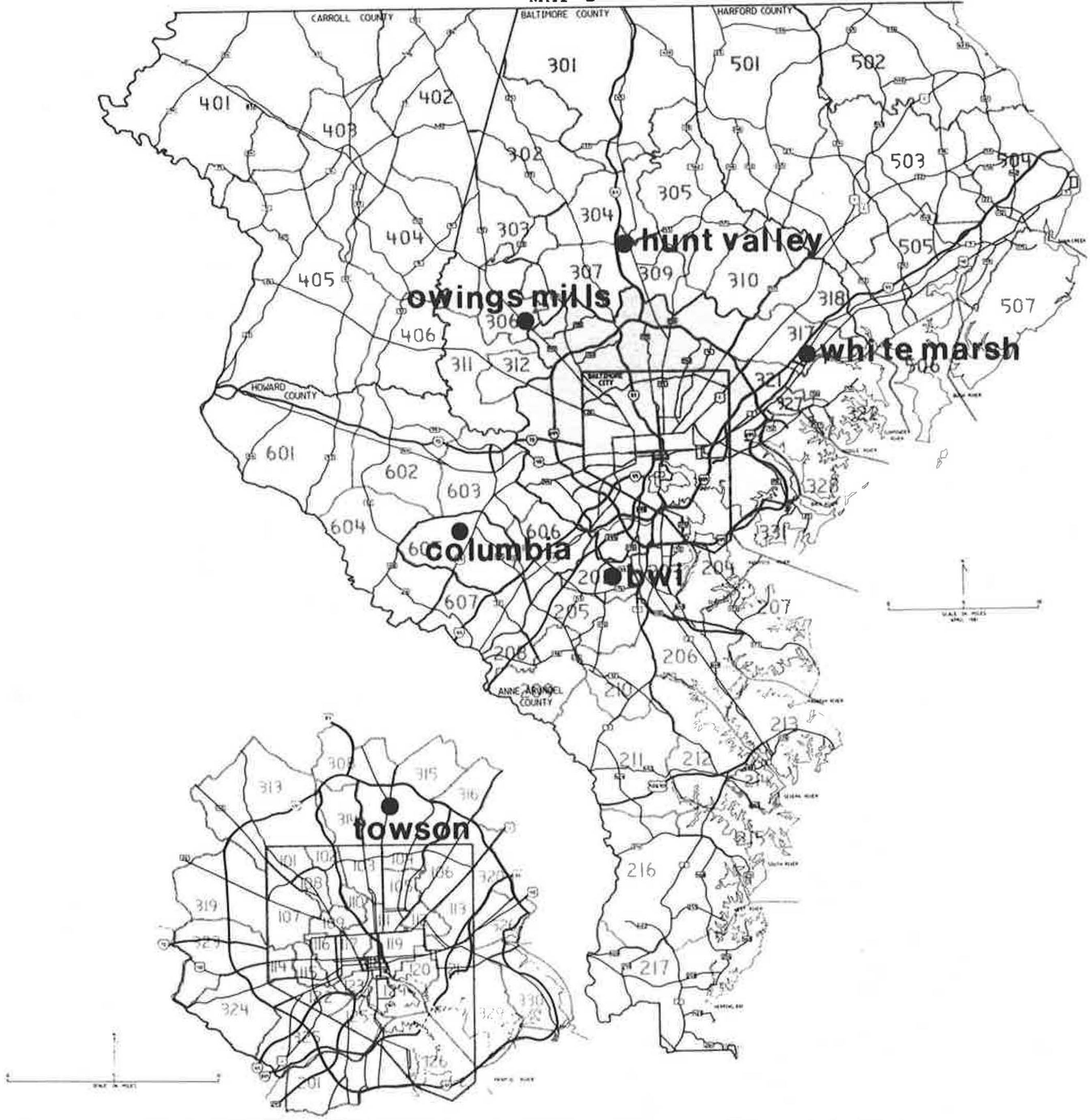
The percentage of commuters in the metropolitan area driving alone grew from 60 to 74 percent between 1980 and 1988, whereas the percentage of commuters in car and vanpools declined from 22 to only 10 percent (*14*). Transit ridership declined from 101.9 million riders in 1980 to 75.0 million in 1985, a decline of 26.4 percent (*15*). In Baltimore City, the percentage driving alone increased from 45 to 56 percent between 1980 and 1988, whereas the percentage using car and vanpools decreased from 20 to 10 percent. The abundance of motor fuels and the decrease in the real prices of fuels during the 1980s contributed to these trends in mode choice.

ACCESSIBILITY ANALYSIS

The intent of the accessibility analysis was to delve into the spatial associations between employment and accessibility to jobs with public transportation. Simulated unconstrained transit travel time data for 1985 were available from BRCOG and were used to calculate a measure of transit inaccessibility to all suburban activity center RPDs from each city RPD. The simulated transit times represented unconstrained or free-flow running times only. No waiting, walking, or transfer times were included, which vary significantly by time of day and add greatly to the total travel time by transit. Simulated peak-hour travel times were not available for various years at the time of this analysis. A measure of relative inaccessibility to individual activity centers through time could not be calculated.

The total travel times from each city RPD to all of the suburban activity center RPDs were used as a measure of

MAP 1



REGIONAL PLANNING DISTRICTS

BALTIMORE CITY

101 UPPER PARK HEIGHTS
102 MOUNT WASHINGTON
103 ROLAND PARK
104 CHINQUAPIN
105 GOVANS-NORTHWOOD
106 HAMILTON
107 FOREST PARK
108 LOWER PARK HEIGHTS
109 DRUID HILL
110 HAMPDEN
111 WAVERLY
112 CLIFTON
113 GARDENVILLE
114 TEN HILLS
115 IRVINGTON
116 ROSEMONT
117 WEST BALTIMORE
118 METROCENTER
119 EAST BALTIMORE
120 HIGHLANDTOWN
121 CANTON
122 MORRELL PARK
123 CARROLL PARK
124 SOUTH BALTIMORE
125 CHERRY HILL
126 BROOKLYN

ANNE ARUNDEL COUNTY

201 BROOKLYN HEIGHTS
202 FRIENDSHIP
203 GLEN BURNIE
204 MARLEY NECK
205 STEWART CORNER
206 SEVERNA PARK
207 MOUNTAIN ROAD
208 MARYLAND CITY
209 FORT MEADE
210 ODENTON
211 CROFTON
212 EPPING FOREST
213 BROADNECK
214 ANNAPOLIS
215 HILLSMERE
216 DAVIDSONVILLE
217 DEALE

BALTIMORE COUNTY

301 HEREFORD-MARYLAND LINE
302 PRETTYBOY
303 FOWBLESBURG
304 SPARKS
305 JACKSONVILLE
306 REISTERSTOWN-OWINGS MILLS
307 CHESTNUT RIDGE
308 LUTHERVILLE
309 COCKEYSVILLE-TIMONIUM
310 FORK
311 HARRISONVILLE
312 RANDALLSTOWN
313 PIKESVILLE
314 RUXTON
315 TOWSON
316 PARKVILLE
317 PERRY HALL-WHITE MARSH
318 KINGSVILLE
319 LOCHEARN
320 OVERLEA
321 ROSSVILLE
322 WINDLASS
323 SECURITY
324 CATONSVILLE
325 ARBUTUS-LANDSDOWNE
326 ROSEDALE
327 MIDDLE RIVER
328 ESSEX
329 DUNDALK-TURNERS STATION
330 NORTH POINT
331 EDGEMERE

CARROLL COUNTY

401 TANEYTOWN
402 MANCHESTER
403 WESTMINSTER
404 FINKSBURG
405 MOUNT AIRY
406 ELDERSBURG

HARFORD COUNTY

501 JARRETTSVILLE-NORRISVILLE
502 CARDIFF-DARLINGTON
503 BEL AIR-FALLSTON
504 ABERDEEN-HAVRE DE GRACE
505 EDGEWOOD-JOPPA
506 ARMY CHEMICAL CENTER
507 ABERDEEN PROVING GROUNDS

HOWARD COUNTY

601 COOKSVILLE
602 WEST FRIENDSHIP
603 ELLICOTT CITY
604 CLARKSVILLE
605 COLUMBIA
606 ELKRIDGE
607 LAUREL

FIGURE 1 Suburban activity centers.

relative inaccessibility from areas within the city. The measure is calculated using the following formula:

$$Ai = \sum_{j=1}^{n} \mathrm{TT}ij \quad (1)$$

where

Ai = relative accessibility from city RPDi to all suburban RPDj's (total travel times),
TTij = travel time between RPDi and RPDj,
$i = (1, \ldots, m)$, and
$j = (1, \ldots, n)$.

The RPDs in a distinct cluster of greatest total travel time to all suburban activity center RPDs were then mapped to show the spatial pattern of inaccessibility.

The areas of relative inaccessibility by transit are in northeast and east Baltimore because of the distance between these areas and activity centers primarily west and south of the city (Figure 2). The CBD and immediate environs are areas of high accessibility because a large amount of transit service begins and ends there. The southwestern tier of RPDs is a significant area of relative inaccessibility because of the long distances from the northern activity centers and because of the absence of transit links to the Columbia and Route 1 activity center in 1985.

For selected pairs of city and suburban RPDs, average travel times by transit in 1985 and automobile in 1986 along with ratios of transit to automobile travel times in both directions were calculated. The selected RPDs consisted of six city RPDs and three suburban activity center RPDs that had substantial amounts of employment and labor force. The city RPDs were

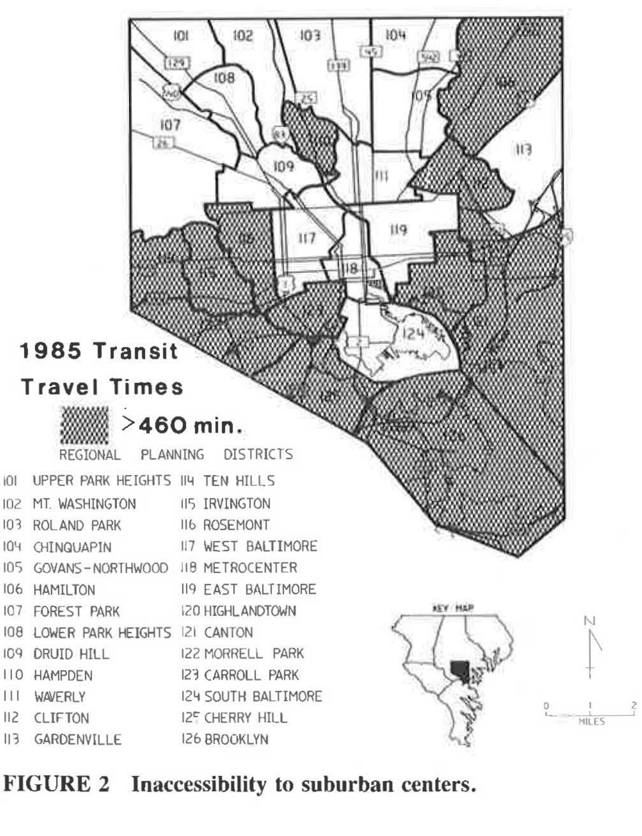


FIGURE 2 Inaccessibility to suburban centers.

also characterized by low median household income and relative inaccessibility. The travel time ratios were compared to discern differences between suburb-to-city and city-to-suburb transit travel times. Transit travel times (running times only) were approximately three times as long as automobile times and ratios of transit to automobile travel time were generally greater for city-to-suburb than for suburb-to-city travel.

The first implication from this analyses is that residents of relatively inaccessible areas of the city are faced with longer transit travel times to suburban activity centers than other city residents. The second implication is that transit-dependent residents of these inaccessible areas often face longer travel times for the reverse commute than do suburbanites commuting by transit to the city. Travel to work generally occurs during a more constrained time period than the trip home. Many low-wage jobs have nighttime shifts when transit is less available. Thus, longer times for the reverse commute to work are an undue burden on transit-dependent, low-wage labor living in the more inaccessible areas of the city.

ATTITUDE SURVEY

A survey of low-wage unemployed residents of Baltimore City was conducted to provide insight into previous job commuting behavior and the perceptions about reverse commuting to suburban jobs. The questionnaires were administered to unemployed workers who applied for unemployment insurance through the Maryland Office of Unemployment Insurance or applied for job training and placement assistance through the Baltimore City Office of Employment Development. The survey results should not be considered as representative of all low-wage unemployed labor in Baltimore City.

Those respondents who stated on the questionnaire that they earned more than $20,000/year were excluded from the sample. The completed questionnaires totaled 528, and 58 percent of these came from the Office of Employment Development; the rest came from the Office of Unemployment Insurance.

A substantial portion of the questionnaire was devoted to demographic characteristics of the respondents. The majority of respondents were in between 25 and 39 years old. Relatively few were younger than 18 or older than 54. The majority of respondents—51 percent—indicated that they were female. Forty-three percent indicated that they were male and 6 percent did not respond to the question about sex. The majority of respondents—69 percent—described themselves as black. Sixteen percent described themselves as white, and other races constituted only 2 percent. Thirteen percent did not respond to the question about race. The median size of the immediate family was 2.5 members. Almost 72 percent of the respondents reported being high school graduates. Fifty-three percent of respondents reported special skills such as technical, administrative, and mechanical. The respondents' occupations were categorized as follows: 19.3 percent in secretarial and clerical jobs, 35.6 percent in sales and services, and 44.7 percent in construction, general labor and mechanical.

Only 29 percent of the respondents reported owning at least one automobile; the remainder, 71 percent, had no automobile. The median wage at the previous job was $6/hr. More than half of the respondents reported traveling less than 10 mi, but 25.3 percent did not respond to this question. The remainder traveled more than 10 mi. Travel time is usually reported more accurately and the travel time for all modes ranged from 1 min to 1.5 hr. The modal and median travel times were approximately 30 min.

Approximately 19 percent of respondents took the automobile exclusively to a previous job; 10 percent took the automobile in combination with transit or paratransit; 24 percent took some combination of transit and paratransit modes; and 35 percent took just transit to commute to work. Few respondents used carpools or vanpools. Ridesharers in the metropolitan area have been overwhelmingly white, middle- to upper-income professional employees (*16*). Low-income commuters have not participated greatly in ridesharing despite its financial advantages.

Low-wage urban labor used a wide variety of modes to commute primarily to jobs in the city, but there was a predominant reliance on transit and an assortment of paratransit modes. It should be noted that the selected combinations of modes were not necessarily used for each work trip.

When asked if respondents would take a job at each of the six activity centers, earning the same wage they did when employed, 28.3 percent stated they would not work at any of the activity centers, 14.6 percent stated they would accept a job at each one. Almost 9 percent stated they would work only in Towson. Owings Mills and Towson were selected by 3.8 percent, and Hunt Valley, Towson, and Owings Mills were selected by 3.2 percent. The other activity centers singly, or in combination, were selected consistently by less than 2 percent of the respondents. Only 1½ percent did not respond to the question.

Almost a third of the respondents would not commute the long distances to jobs at suburban centers that pay similar wages to those in the city. The shorter distances to Towson, Hunt Valley, and Owings Mills from the northern areas of the city accounted for the higher percentages of selection.

Those who would not accept a job at an activity center were asked what incentives would be needed in order to accept a job. Higher pay was selected by 17.3 percent of respondents. Almost 15 percent selected higher pay and more convenient transportation. Another 10 percent selected a combination of higher pay, flexible work schedule, and more convenient transportation. More convenient transportation exclusively was selected by 8.7 percent; higher pay, more convenient transportation, and cheaper transportation were selected by another 6.8 percent. Child care and other incentives elicited insignificant responses. Approximately 18 percent did not address this question at all, either because they chose not to or because they had already stated they would accept a job at each activity center.

It is evident that higher pay is a critical factor in increasing the accessibility of low-wage city labor to suburban employment. Demand for transportation services that are convenient for commuting to the suburbs is associated with the desire for higher pay.

One question presented a scenario of an available job in the suburbs accessible by private automobile, bus, or van service. The monetary costs, travel times, and waiting times for each alternative were given. A fourth alternative was to not take the job because the trip was too long or costly with any of the transportation alternatives. In response 12.1 percent stated they would not take the trip at all. Approximately 37 percent stated they would take the automobile, and 12.5 percent would take the van. The bus alternative was chosen by 23.7 percent of the respondents. Although the question asked respondents to choose only one of the three options, 5.3 percent chose both van and bus alternatives as the preferred means of transportation. A majority of respondents selected the automobile or van as the desired mode for commuting to suburban jobs. Approximately 10 percent of the respondents did not address the question or did not answer meaningfully.

The next question asked respondents who chose the automobile what incentives they would require to switch to the van or bus. Roughly 37 percent did not respond, either because they did not choose the automobile or because they chose not to answer the question. Some respondents apparently selected incentives even after choosing bus or van. Almost 15 percent stated they would not switch from the automobile, regardless of incentives. The single incentive for switching chosen most often was faster bus or van (7.4 percent). More frequent bus or van service (4.9 percent) and less waiting time (4.9 percent) were next in importance. Cheaper bus or van was picked by only 3 percent of respondents. The rest of the responses involved combinations of incentives. The answers to this question imply that higher-quality public transportation is important for diverting automobile users to transit or paratransit. Many respondents perceive that an automobile is preferable for commuting to a suburban job despite its costs and that transit and paratransit modes are currently inconvenient for that purpose.

To gain a deeper understanding of the relationships among the responses, all of the survey responses were subjected to a factor analysis. All of the variables were reduced to nine factors with Eigen values greater than one. After a varimax rotation of the factors, only the first four factors with the highest Eigen values had loadings that could be interpreted meaningfully (Table 1).

The variables of family size, wages paid in last job, and travel distance to work loaded positively and strongly on the first factor, implying that there are positive relationships among family size, wages, and travel distance. Workers with larger families apparently travel longer distances to earn higher wages.

The second factor exhibited positive loadings by mode of travel to work and automobile ownership. Those who own automobiles use them to travel to work. Those who do not own automobiles use other modes to travel to work. Because wages did not load on this factor significantly, automobile ownership apparently does not vary by level of wage within this low-wage group. It has been shown in other studies that automobile ownership and use are directly and positively related to income, but appears not to be directly related to the small variation in wages paid to low-wage urban labor. The variables of mode choice and travel time to work did not relate to demographic, education, or wage characteristics. Evidently, these variables are a function of location of job opportunities and presence of transportation alternatives.

The third factor related the type of occupation in the last job to the type of new occupation sought. The fourth factor exhibited strong, positive loadings by the variables: sex and race (the majority of respondents were black and female).

TABLE 1 FACTOR ANALYSIS OF SURVEY RESPONSES: ROTATED FACTOR LOADINGS (VARIMAX)

Variables	Factors I	II	III	IV
1) Previous Occupation			.81	
2) Occupation Sought			.75	
3) Residence Zip				
4) Work Area				
5) Work Zip				
6) Own Car		.76		
7) Commute Modes		.83		
8) Travel Distance	.76			
9) Travel Time				
10) Fare				
11) Accept Suburban Job				
12) Job Incentives				
13) Suburban Mode				
14) Mode Incentives				
15) Family Size	.87			
16) Age				
17) Sex				.80
18) Race				.73
19) Education				
20) Skills				
21) Wages	.80			
22) Wages/Family Size				
Cumulative Proportion of Total Variance	16.1%	23.3%	30.4%	37.0%

Note: Only loadings ± 0.7 are shown.

ENERGY CONSUMPTION ANALYSIS

The intent of the energy consumption analysis was to illustrate the impacts of longer reverse commute trips to suburban jobs and of various public transportation scenarios to increase accessibility. The analysis followed the framework established by Lutin for estimating energy consumption for work trips in New Jersey (*8*). Energy consumption is a function of the total number of work trips, work trip length, mode split, energy consumption by mode, and load factor (occupancy). The expression of this function is as follows:

$$Em = (Wb)(Lb)[(WPm)(em)/lm] \quad (2)$$

where

- Em = daily work trip energy use by Mode m;
- Wb = daily work trips generated in Baltimore City;
- Lb = average work trip length in Baltimore City;
- WPm = percentage of work trips by Mode m;
- em = energy consumption (gal) per vehicle mile by Mode m; and
- lm = load factor for Mode m.

Energy consumption by mode was estimated for two modes: automobile and van and transit (bus and rail). The values for daily work trips and average length of trip came from BRCOG's 1986 traffic simulation model. The percentages of work trips by mode (mode split) were derived from the 1988 BRCOG household survey of commuting in the metropolitan area (*14*). BRCOG estimated that 468,564 daily work trips were generated in Baltimore City in 1986. The average trip length to destinations in the city and to destinations within the region were weighted by the household survey's work trip destination percentages, resulting in an average trip length of 4.68 mi. Trip length was assumed to be the same for automobile and van and transit.

The household survey also found that 56.5 percent of Baltimore City commuters drove alone and 9.9 percent were in carpools or vanpools, constituting 66.4 percent of all work trips. Transit accounted for 24.2 percent of work trips.

The data for energy consumption by mode came from FHWA highway statistics for 1986 (*17*). The data are for fuel consumption on highways; yet, the data were considered reasonably representative. Energy consumption for transit consisted of the average operating fuel consumption for buses. It was assumed for the sake of simplicity that rail transit consumed diesel fuel at the same rate as buses. Automobiles achieved on average 18.32 mi/gal or consumed 0.055/gal/mi; transit achieved 5.71 mi/gal, or consumed 0.175 gal/mi.

The load factor (occupancy) for transit was calculated from Maryland Mass Transit Administration passenger-mile and revenue-mile data reported to the U.S. Department of Transportation (*18*). The average number of passengers per vehicle was calculated to be 15.5. This calculation may underestimate the transit load factor in Baltimore City, because the service area includes suburban Baltimore County as well. Data for Baltimore City alone were not available. The load factor for automobiles was calculated using data from the BRCOG traffic simulation, the household survey, and a study done for UMTA on ridesharing (*16*). The automobile and van load factor was calculated to be 1.14.

Energy consumption by the two modes was calculated for five scenarios. The first scenario represents the status quo, and the second represents longer work trips. The second scenario would result if employment opportunities were to continue to migrate to the suburbs and low-wage labor to remain primarily in the city. The percentages used in these scenarios are merely for illustrative and comparative purposes. The three remaining scenarios represent public transportation policies to reduce the energy consumption from longer reverse commute trips. These scenarios are

1. Current values for mode choice, trip distance, and load factors—essentially the status quo.
2. Ten percent increase in average trip distance for all trips from 4.68 to 5.15 mi (5.15 mi used for remaining scenarios).
3. Ten percent increase in transit ridership (diversion of 3.6 percent of automobile and van trips to transit) and transit load factor remains at 15.5.
4. Ten percent increase in transit ridership and a 20 percent increase in transit load factors.
5. Ten percent increase in automobile and van load factor (decrease in automobile and van trips by 8.8 percent).

The changes in the values and the calculated total energy consumption for work trips for each scenario are shown in Table 2.

The most effective of the three public transportation scenarios is Scenario 5, which would increase the automobile and van load factor by 10 percent, because it would result in almost negating the increased energy consumption from the increase in work trip length. A 10 percent increase in automobile and

TABLE 2 SCENARIOS OF WORK-TRIP ENERGY CONSUMPTION: BALTIMORE CITY

Scenarios		Trip Distance [Miles]	Mode Split	Load Factor	Energy Consumption [Gallons]
Scenario I (status quo)	auto/van:	4.68	.664	1.14	70,249
	transit:		.242	15.5	5,992
					76,241
Scenario II (inc. distance)	auto/van:	5.15	.664	1.14	77,304
	transit:		.242	15.5	6,593
					83,897
Scenario III (inc. transit)	auto/van:	5.15	.64	1.14	74,510
	transit:		.266	15.5	7,247
					81,757
Scenario IV (inc. transit/ inc. load)	auto/van:	5.15	.64	1.14	74,510
	transit:		.266	18.6	6,039
					80,549
Scenario V (inc. auto/ van load)	auto/van:	5.15	.664	1.25	70,501
	transit:		.242	15.5	6,593
					77,094

van load factor would result in an 8.1 percent decrease in fuel consumption. Scenario 5 would achieve the lowest fuel consumption results because two-thirds of total work trips are by automobile and van, and a 10 percent increase in automobile and van occupancy would reduce the number of automobile and van trips more than a 10 percent increase in transit ridership would. The effectiveness of Scenario 5 would be even greater for suburban jurisdictions in which automobile and van use is even more dominant.

Although it would dramatically increase transit ridership and load factors would clearly be difficult given recent trends, Scenario 5 would not necessarily be easy to achieve either because ridesharing has decreased in popularity in Baltimore during the 1980s. Yet, ridesharing incentives, such as high-occupancy-vehicle (HOV) lanes, HOV preferential parking, and mixed-use zoning, have not yet been widely instituted in the Baltimore metropolitan area.

These scenarios are not mutually exclusive. Incentives to increase automobile and van occupancy could also enlarge transit vehicle occupancy as well. The result would decrease energy consumption further. Yet, it is clear that expanding transit service to more-distant suburbs will not reduce energy consumption for work trips if, as a result of flow density, transit ridership is low.

Another scenario that is probably most effective for reducing energy consumption for work trips, but one more difficult to implement, is to move from Scenario 2 to Scenario 1. Expanding job opportunities in the inner-city and constructing abundant low-income housing near suburban activity centers would reduce work-trip lengths, thus increasing accessibility to jobs and reducing energy consumption.

CONCLUSIONS AND RECOMMENDATIONS

Job opportunities for low-wage labor have decreased in cities and increased in the suburbs. The jobs at suburban activity centers in the Baltimore metropolitan area are relatively inaccessible in terms of travel time by transit from many areas of Baltimore City. Reverse commute transit travel times are generally greater than suburb-to-city travel times. Thus, low-wage urban labor's inaccessibility to job opportunities and the potential for increased energy consumption have grown.

Low-wage urban labor has used primarily transit and paratransit modes for commuting to jobs in the city, but many desire higher wages and automobiles or higher-quality public transportation for commuting to suburban jobs. To increase inaccessibility of the low-wage unemployed to suburban jobs and to conserve energy, low-wage labor should have more opportunities to live closer to suburban activity centers and use an assortment of reverse commute services. Public policies that promote more low-income housing in mixed-use developments and greater HOV use during the commute to work would result in substantial energy savings.

Additional paratransit modes, such as carpools, vanpools, jitneys, or shared-ride taxis, coupled with HOV lanes, HOV preferential parking, increased fuel taxes, and congestion pricing would increase automobile and van occupancy. Paratransit can provide door-to-door service to dispersed origins and destinations. During off-peak hours paratransit can provide cost effectiveness and energy efficiency. Exclusive guideway transit systems may be appropriate for some high-density corridors of residential and commercial development, although they incur high capital costs and tend to be geographically inflexible.

State and local government should reduce the regulations that inhibit the private sector from operating public transportation services and should create more opportunities for private-sector services under contract. Serious thought should be given to creating busways and HOV lanes that can also be used cost-effectively for the reverse commute. Government and private-sector employers should aggressively market van services, carpooling, and vanpooling to the urban labor force. If labor is in short supply, employers should pay the financial incentives to attract labor to suburban jobs and to reverse commute services.

ACKNOWLEDGMENTS

This research was supported by grants from FTA's University Research and Training Program and the Maryland Energy

Office with funding from the Maryland Energy Overcharge Restitution Trust Fund and U.S. Department of Energy.

REFERENCES

1. R. Cervero. *Suburban Gridlock*. Center for Urban Policy Research, New Brunswick, N.J., 1986.
2. J. R. Ottensman. Changes in Accessibility to Employment in an Urban Area: Milwaukee, 1927–1963. *Professional Geographer*, Vol. 32, No. 4, 1980, pp. 421–430.
3. M. A. Hughes. *Poverty in Cities*. National League of Cities, Washington, D.C., 1989.
4. C. B. Notess. Travel in the Black Ghetto. In *Highway Research Record 403*, HRB, National Research Council, Washington, D.C., 1972, pp. 49–50.
5. P. Hughes. *Utilizing the Center City Transportation Program to Increase the Effectiveness of Federal Manpower Programs*. National Urban Coalition, Washington, D.C., Feb. 1970.
6. H. Bigler and E. Keith. Transporting the Poor to Work. *Manpower*, Vol. 4, No. 5, May 1972, pp. 2–8.
7. J. E. Anderson. What Determines Transit Energy Use. *Journal of Advanced Transportation*, Vol. 22, No. 2, 1988, pp. 108–133.
8. J. M. Lutin. Energy Savings for Work Trips: Analysis of Alternative Commuting Patterns for New Jersey. In *Transportation Research Record 561*, TRB, National Research Council, Washington, D.C., 1976, pp. 23–36.
9. M. Pikarsky. Land Use and Transportation in an Energy Efficient Society. In *Special Report 183: Transportation and Land Development Conference Proceedings*, TRB, National Research Council, Washington, D.C., 1978, pp. 11–16.
10. W. Cox. Opening Remarks. In *Special Report 203: Proceedings of the Conference on Energy Contingency Planning in Urban Areas*, TRB, National Research Council, Washington, D.C., April 6–9, 1983, pp. 17–18.
11. *State of Maryland Civilian Labor Force, Employment, and Unemployment by Place of Residence*, Office of Labor Market Analysis, Maryland Department of Economic and Employment Development, May 1991.
12. *Geographic Profile of Employment and Unemployment, 1988*. Bureau of Labor Statistics, U.S. Department of Labor, May 1989.
13. *Round 3-A Cooperative Forecasts*. Baltimore Regional Planning Council, Md., 1988.
14. *1988 Household/Travel Survey Results for the Baltimore Region*. Transportation Planning Division, Baltimore Regional Council of Governments, Md., Aug. 1990.
15. C. Harrold. *Profiles of Travel Trends: A Statistical Abstract for 1980–1988*. Baltimore Regional Council of Governments, Md., June 1990.
16. M. Ayele and J. Byun. *A Study to Assess the Importance of Personal, Social, Psychological and Other Factors in Ridesharing Programs*. UMTA, U.S. Department of Transportation, 1984.
17. *Statistical Abstract of the United States, 1989*. Bureau of the Census, U.S. Department of Commerce, 1989.
18. *1989 Section 15 Annual Report*. Maryland Mass Transit Administration, Oct. 1989.

Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Current Use of Geographic Information Systems in Transit Planning

CAROL L. SCHWEIGER

The advent of geographic information systems (GIS) has facilitated the integration of data with geographic elements to perform analysis in a variety of disciplines, including transportation. The unique ability of GIS to handle complex spatial relationships makes it a natural tool to use in the planning and analysis of transportation systems, specifically public transportation systems. The current use of GIS technology in public transit agencies and metropolitan planning organizations (MPOs) for transportation planning and analysis was investigated. A total of 74 telephone interviews were conducted with 67 organizations across 30 states—46 transit agencies (including both operators and oversight agencies) and 21 MPOs. Of the transit agencies and MPOs contacted, most were located in the 30 largest metropolitan areas in the United States (based on the 1990 Census). However, several small transit agencies (having less than 50 buses) and MPOs were contacted to provide a broader view of GIS use in transit planning practice. The results of this investigation show that GIS is currently being used or being implemented for a wide variety of applications, in a wide variety of organizational settings, and for a wide variety of reasons. The implementation of GIS for transit is driven primarily by two factors: budgets and the need to integrate data from several sources to perform comprehensive analyses. Another significant issue is the use of spatial data, which often requires a significant "clean-up" activity that has to take place before the data are fully usable.

Geographic information systems (GIS) is a rapidly developing field of information management that enables users to store, retrieve, edit, manipulate, and graphically display spatially referenced data, and to integrate such data from multiple data bases using both topological and attribute information. GIS has the potential to significantly increase the quality of urban transportation planning data while reducing the cost of data collection and preparation by enabling transit and other local agencies to share and use each other's data bases.

The purpose of this study was to explore the benefits and obstacles to the use of GIS in transit planning. Specifically, this study investigated the current use of GIS in transit planning. The major objectives of the investigation were to identify

- The current penetration of GIS technology into transit planning practice,
- The major issues and problems faced by these agencies in adopting GIS technology, and
- Specific GIS software products currently being used by transit agencies and their rationale for using them.

EG&G Dynatrend, Inc., 21 Cabot Road, Woburn, Mass. 01801.

DEFINITION OF GIS

GIS has been defined in many ways by the "experts" in the field. The following definition combines those previous definitions by presenting the two most important characteristics of GIS that separate it from other computerized graphical systems:

> A GIS is a tool that provides data base management capabilities (including capture, selection, storage, editing, querying, retrieval, and reporting functions) for and display of spatial data, and provides the ability to perform analysis of geographic features (points, lines, and polygons) based on their explicit relationship to each other.

An important concept that makes GIS different from other computerized graphical systems is topology. Topology is defined (*1*) as the spatial relationships between connecting or adjacent spatial objects (e.g., points, lines, and polygons). Topological relationships are built from simple elements into complex elements: points (simplest elements), lines (sets of connected points), and polygons (closed sets of connected lines). For example, the topology of a line includes its "from" and "to" points and its left and right polygons. GIS has the ability to extract information from one layer of topology, based on its relationship to another layer, and to integrate information from various topological layers based on their relationships to each other.

GIS is the most sophisticated member of a family of computerized graphical systems that have varying degrees of capabilities in data base management and spatial functions. This family of graphical systems consist of

- Computer-aided drafting and design (CADD),
- Automated mapping (AM),
- Thematic mapping, and
- GIS—raster-based GIS and vector-based GIS.

According to Huxhold (*2*, p. 35), CADD systems provide the ability

> to interact with a visual image of a drawing by creating, editing, and manipulating lines, symbols, and text. Automated mapping software generally has the same functions as CADD software; however, CADD systems are normally used for architectural and engineering drawings, while automated mapping is used for mapping. An example of an application of automated mapping is displaying vehicle locations on an electronic map as part of an automated vehicle location (AVL) system.

Again, Huxhold (*2*, p. 35, p. 27) states:

> Functions specific to mapping include: coordinate transformation, map scale conversion, coordinate geometry, edge-matching and other related geometric operations. . . . An enhancement to automated mapping systems is the automated mapping and facilities management (AM/FM) system. AM/FM systems utilize a database capability to store additional information about the mapped objects (physical features such as water valves, gas mains, meters, transformers, etc.) and link those data to the map information, but generally do not include spatial analysis capabilities or topological data structures such as those found in GIS.

Thematic mapping can add colors, labels, and other identifying features to map entities based on attributes [descriptive characteristics of a feature (*2*)] associated with that entity. Thus, as the term suggests, thematic mapping emphasizes a particular theme on the map by focusing attention on specific attributes of the map entities.

GIS differs from those other graphical systems in its ability to handle both attributes and topology. There are two types of GIS that handle attributes and topology differently: vector-based and raster-based GIS. (The majority of GIS applications in transit planning are vector based.) Vector-based GIS (*1*) represents map features by *x*,*y* coordinates. Attributes are associated with the feature, as opposed to a raster-based GIS, in which attributes are associated with a grid cell (an individual point). Thus, vector-based GIS deals explicitly with topology, whereas raster-based does not.

Overall functional capabilities of GIS consist of data capture, storage and maintenance, and analysis and output. Data capture can be digitized or performed using graphical data from existing sources and attribute data from existing files or manually entered. Data storage and management consist of file management and editing. Data analysis consists of data base query, spatial analysis, and modeling. Data output can be generated in the form of maps and reports.

STUDY APPROACH

The approach to performing this investigation was first to design a set of questions (initially developed by GIS/Trans, Ltd.) to be asked during a telephone interview, and to develop a list of transit agencies and Metropolitan Planning Organizations (MPOs) that would be contacted. The final set of questions asked during the telephone interviews is shown in Figure 1.

A list of potential contacts was developed by identifying transit agencies and MPOs in the 30 largest metropolitan areas in the United States (based on the 1990 Census). To provide a broader view of GIS use in transit planning, several small transit agencies (having less than 50 buses) and MPOs were added to the list. Appropriate contacts within those organizations were identified either before the interview or by the organization during initial contact. The final list of transit agency and MPO contacts is shown in Table 1, along with the respective 1990 population, and the size with respect to number of transit vehicles. (Because of time constraints, not all transit agencies and MPOs in the 30 largest metropolitan areas were contacted.)

Next, three "pilot" interviews were conducted with New York City Transit Authority, Omaha–Council Bluffs MPO, and Southern California Rapid Transit District, all of which were selected from the list of contacts. Based on the results of the pilot interviews, the full set of telephone interviews was conducted. The results of the interviews were reviewed and analyzed and appear below. A Federal Transit Administration (FTA) report entitled *Current Use of Geographic Information Systems* (*3*) contains a complete presentation of the results.

SUMMARY OF DATA COLLECTED

During the telephone interviews, data were collected in the following categories:

- Current use of GIS in terms of application areas, software, and perceived problems and benefits;
- Spatial data resources in terms of data types, sources, quality, and clean-up time;
- Knowledge of other agencies active in GIS;
- GIS implementation plans in terms of potential application areas, potential software, organizational issues, and training; and
- The interviewee's definition of GIS was not being used.

USE OF GIS IN TRANSIT PLANNING

A total of 74 telephone interviews were conducted with 67 various organizations across 30 states—46 transit agencies (including 40 operators and 6 oversight agencies) and 21 MPOs. Of the 67 organizations interviewed, 36 currently claim to have GIS. Of the 46 transit agencies, 21 have GIS (46 percent), and of the 21 MPOs, 15 have GIS (71 percent). These figures represent a significant use of GIS, particularly in MPOs, which do more than just transportation analysis. Generally, the current use of GIS in transit agencies is based on the need to integrate data from various sources to perform comprehensive transit planning and analysis. The current use of GIS in MPOs is based on wider requirements for areas such as land use planning, population and employment projections, zoning analysis, and growth management.

Current Range of Applications

GIS is currently being used in many transit planning applications by transit agencies and MPOs. However, in most cases, GIS is not being used as a substitute for analytical modeling, which is an integral part of most planning activities; rather, it is being used as a tool to augment the modeling. The following are five major application areas in which GIS is being used (the number of organizations claiming to use GIS in the application area is in parentheses):

1. Transit analysis (30):

–Transit ridership forecasting is an important component of the traditional four-step transportation planning process

1. Interviewer:

2. Date of contact:

3. Name of organization:

4. Initial Contact:

   Name:
   Title:
   Address:
   Phone Number:

A. CURRENT USE OF GIS

1. Does your agency currently use GIS? (Yes/No) (If "No," skip to Section B.)

2. In which areas of your organization is GIS used? (Refer to list of potential application areas.)

   List of potential application areas:

   - Transit ridership forecasting, service planning, market analysis
   - Transit scheduling and run-cutting
   - Map products design & publishing (for example: system maps, route schedules and maps, operator maps)
   - Telephone-based customer information services
   - Ridematching (for car & van pools)
   - Transit pass sales
   - Fixed-route transit dispatching
   - Automatic vehicle location
   - Paratransit scheduling & dispatching
   - Fixed facilities and real estate management (for example: bus stops, transit stations, park & ride lots)
   - Police operations
   - Any other functional areas?

3. Which GIS product(s) do you use in these areas? (Try to obtain model and version number, if this is known.)

   List of GIS (and related) products:

   - ARC/INFO
   - Intergraph
   - Intergraph
   - Caliper Corp. (TransCAD, GIS Plus)
   - McDonnell Douglas (GDS)
   - G5 (GeoSQL)
   - MapInfo
   - Atlas
   - GeoVision
   - SPANS
   - AutoCAD
   - EMME/2
   - TRANPLAN
   - Others?

FIGURE 1 Interview questions. (*continued on next page*)

4. Why did you choose this product?

5. When was the product installed?

6. How has GIS use benefitted your organization?

7. What problems have been encountered with its use?

8. What improvements would you like to see to your GIS capabilities?

9. Are you presently considering expansion of your GIS capabilities?

10. How many individuals in your organization have GIS training?

11. How many individuals in your organization have GIS as part of their job title or job description?

B. SPATIAL DATA RESOURCES

1. Do you have street network data for your service area stored on computer?

2. What is the source of this data?

   List of potential data sources:

   - DIME (1980 U.S. Census)
   - TIGER (1990 U.S. Census)
   - U.S. Geological Survey (Digital Line Graphs)
   - ETAK
   - State DOTs
   - Other sources?
   - Digitized in-house

3. How much staff time have you devoted to cleaning and correcting this data?

4. What is your appraisal of this data's current quality?

5. Do you have any transit system data stored on computer?

6. What types of data are stored electronically?

   List of transit system data types:

   - Rail transit routes
   - Bus transit routes
   - Rights-of-way
   - Bus stops
   - Bus timepoints
   - AVL signposts
   - Traffic signals (e.g., vehicle-actuated signals)
   - Transit stations
   - Park-and-ride lots
   - Vehicle maintenance and storage facilities (e.g., bus garages, rail vehicle shops, yards, etc.)
   - Political boundaries
   - Traffic analysis zone boundaries
   - Census tract boundaries
   - Accident locations
   - Incidents requiring police response
   - Other data?

7. Does this computer-based data include graphical location information? (For example, latitude & longitude coordinates, digitizer inches)

C. OTHER ACTIVE AGENCIES

1. Do you know of any other transit agencies or MPOs who are presently using or considering implementation of GIS?

FIGURE 1 *(continued)*

2. Who may I contact in these agencies?

   Name:
   Title:
   Organization:
   Phone Number:

D. GIS IMPLEMENTATION PLANS

1. Are you presently considering implementation of GIS for any (other) applications within your organization? (Yes/No) (If "No," skip to end of interview.)

2. Which areas are you considering for implementation of GIS (Refer to list of potential application areas.)

3. Do you already have a particular GIS product in mind for application? (Yes/No) Which product? (Try to obtain model and version number, if this is known.)

4. For what reasons are you considering GIS implementation at the present time?

5. Are you considering a pilot study to introduce GIS to your organization?

6. Are you presently developing an organization-wide GIS implementation plan?

7. What obstacles do you anticipate facing in the implementation of GIS?

8. Are you considering sending any staff to introductory training or workshops on GIS?

9. What department do these personnel work in?

FIGURE 1 *(continued)*

(trip generation, trip distribution, modal split, and network assignment). "Transit patronage forecasts are the product of a sequence of models used to analyze and predict aggregate travel volume in an urban area, the geographic distribution of trip-making, the level of transit travel in specific corridors, and ultimately, patronage on individual routes or services" (*4*, p. 22).

–Service planning refers to the design and analysis of transit service, including route structure (network), headways, station spacing, and service type (e.g., express service). For an existing transit system, service planning would include the design and analysis of modifications to the existing service.

–Market analysis is the examination of demographic characteristics, such as population, employment, and vehicle ownership, in relation to the transit service being provided. Market or demographic analysis is also an integral part of the four-step planning process, particularly in performing trip generation and modal split.

2. Design and publication of map products (21). Design and publication of map products refers to the creation and printing of maps used for transit planning and operations. Examples include transit system maps, maps showing demographic information for a particular service area, transit route maps, and maps for transit operators (i.e., bus drivers).

3. Facilities/land management (16). Facilities/land management refers to the ability to manage facilities and real estate based on several characteristics, including location, inventory, and condition. Facilities can be either fixed, such as rail storage yards, transit stations, park-and-ride lots, and bus stops, or mobile, such as transit stop signs and maps. Real estate management can involve additional characteristics such as owner, lessor, and land use.

4. Telephone-based customer information services (7). Telephone-based customer information services can assist transit riders in their use of transit services by providing information over the telephone. The information given to the customer can be generated by computer software (e.g., a GIS).

5. Transit scheduling and run-cutting (6). Transit scheduling and run-cutting refers to those activities necessary to develop schedules for the operation of transit vehicles. Specifically, run-cutting is "the process of organizing all scheduled trips operated by a transit system into runs" (*4*, p. 110).

Comments of Transit Agencies and MPOs About Current Use of GIS

A number of comments were made by transit agencies and MPOs regarding their current use of GIS in transit planning follow. For example, NYCTA commented that GIS has enabled it to analyze and track proposed capital investment and to produce maps showing demographic, trip, and other information together. Further, the NYCTA is using GIS in the analysis of rapid transit modifications and improved transfer points and connections.

In Houston, both Houston Metro and Houston-Galveston Area Council (H-GAC) are performing transit ridership forecasting, service planning, and market analysis using the same software (Houston Metro's GIS transit applications are currently under development). However, H-GAC is doing service planning for areas outside of Houston Metro's boundaries. H-GAC is using GIS to enhance, not replace, forecasting models (by developing inputs to the models) and to display the results. The primary benefit to using GIS is its visual capability, according to Houston Metro. "We spend a lot of

TABLE 1 LIST OF CONTACTS

LOCATION	ORGANIZATION	ABBREVIATION	TYPE	1990 POPULATION[1]	NO.[2] OF TRANSIT VEHICLES
Atlanta, GA	Atlanta Regional Commission	ARC	MPO	2,833,511	709
	Metropolitan Atlanta Rapid Transit Authority	MARTA	Operator		
Baltimore, MD	Baltimore Regional Council of Governments (COG)		MPO	2,382,172	793
	Mass Transit Administration of Maryland	MTA	Operator		
Bloomington, IN	McLean County Regional Planning Council		MPO		
Boston, MA	Central Transportation Planning Staff	CTPS	Oversight[3]	4,171,643	
	Metropolitan Area Planning Council	MAPC	MPO[4]		
Chicago, IL	Chicago Transit Authority	CTA	Operator	8,065,633	2,761
	Metropolitan Rail	Metra	Operator		383
	Regional Transportation Authority	RTA	Oversight		
Cincinnati, OH	Southwest Ohio Regional Transit Authority	SORTA	Operator	1,744,124	317
Cleveland, OH	Greater Cleveland Regional Transit Authority	GCRTA	Operator	2,759,823	633
	Northeast Ohio Areawide Coordinating Agency	NOACA	MPO		
Columbus, OH	Central Ohio Transit Authority	COTA	Operator	1,377,419	281
Dallas, TX	Dallas Area Rapid Transit	DART	Operator	3,885,415	539
Denver, CO	Regional Transportation District	RTD	Operator	1,848,319	603
Des Moines, IA	Des Moines, City of, Transportation Planning Commission		MPO		
Detroit, MI	City of Detroit DOT		Operator	4,665,236	436
	Southeast Michigan COG	SEMCOG	MPO		
	Suburban Mobility Authority for Regional Transportation	SMART	Operator		202
Green Bay, WI	Brown County Planning Commission		MPO		
Greensboro, NC	Piedmont Triad COG		MPO		
Houston, TX	Houston-Galveston Area Council	H-GAC	MPO	3,711,043	698
	Metropolitan Transit Authority of Harris County	Houston Metro	Operator		
Kalamazoo, MI	Kalamazoo DOT	Metro Transit System	Operator		30
Kansas City, MO	Kansas City Area Transportation Authority	KCATA	Operator	1,566,280	225
	Mid-America Regional Council	MARC	MPO		
Los Angeles, CA	Southern California Rapid Transit District	SCRTD	Operator	14,531,529	2,040
Medford, OR	Rogue Valley Transit District	RVTD	Operator		19
Miami, FL	Miami MPO		MPO	2,643,766	
Milwaukee, WI	Milwaukee County Transit System		Operator	1,607,183	460
Minneapolis, MN	Metropolitan Transit Commission	MTC	Operator	2,464,124	N/A
Mobile, AL	Mobile Transit Authority		Operator		31
Nashville, TN	Metropolitan Transit Authority	MTA	Operator		102

(*continued on next page*)

TABLE 1 *(continued)*

New York, NY	Metropolitan Transportation Authority	MTA	Oversight	18,087,251	
	New York City Transit Authority	NYCTA	Operator		8,131
	Port Authority of New York and New Jersey		Oversight		
	Metropolitan Suburban Bus Authority	MSBA	Operator		N/A
	Long Island Rail Road	LIRR	Operator		1,049
Newark, NJ	New Jersey Transit Corporation	NJT	Operator		2,198
Norfolk, VA	Tidewater Transportation District Commission	TTD	Operator	1,396,107	129
Norwalk, CT	Norwalk Transit District		Operator		18
Omaha, NE	Omaha-Council Bluffs MPO		MPO		
Philadelphia, PA	Delaware Valley Regional Planning Commission	DVRPC	MPO	5,899,345	
	Southeastern Pennsylvania Transportation Authority	SEPTA	Operator		1,570
Phoenix, AZ	City of Phoenix, Public Transit Department		Operator	2,122,101	260
Pittsburgh, PA	Port Authority of Allegheny County	PAT	Operator	2,242,798	842
Portland, ME	Greater Portland Transit District	GPTD	Operator		18
Portland, OR	Portland Metro	Metro	MPO	1,477,895	438
	Tri-County Metropolitan Transportation District of Oregon	Tri-Met	Operator		
Sacramento, CA	Regional Transit District	RTD	Operator	1,481,102	176
San Francisco/ Oakland, CA	Alameda-Contra Costa Transit District	AC Transit	Operator	6,253,311	671
	Bay Area Rapid Transit	BART	Operator		346
	Metropolitan Transportation Commission	MTC	Oversight		
	Golden Gate Bridge, Highway & Transportation District	GGBHTD	Operator		197
San Antonio, TX	San Antonio-Bexar County MPO		MPO	1,302,099	415
	VIA Metropolitan Transit	VIA	Operator		
San Diego, CA	Metropolitan Transportation Development Board	MTDB	Oversight	2,498,016	
	San Diego Association of Governments	SANDAG	MPO		
Seattle, WA	Municipality of Metropolitan Seattle	Seattle Metro	Operator	2,559,164	962
	Puget Sound COG	PSCOG	MPO		
Shreveport, LA	Shreveport Area COG	SACOG	MPO		
St. Louis, MO	Bi-State Development Agency		Operator	2,444,099	597
Tampa, FL	Hillsborough Area Regional Transit Authority	HART	Operator	2,067,959	140
	Tampa Urban Area MPO		MPO		
Washington, DC	Metropolitan Washington COG	WashCOG	MPO	3,923,574	
	Washington Metropolitan Area Transit Authority	WMATA	Operator		1,919

[1] Population listed only for 30 largest metropolitan areas.

[2] Numbers are calculated from 1988 Section 15 data. Total number of vehicles represents all modes, except those operated by a contractor (e.g., purchased service).

[3] CTPS is the technical planning staff for the Boston Region MPO, which is comprised of six agencies with a transportation planning function in the Boston region.

[4] MAPC is one of the agencies with a transportation planning function in the Boston region, and provides local representation to the MPO.

time with area companies marketing our services, and planning services for them, and we are able to produce good zipcode level maps to support it" (Jim Bunch, telephone conversation with author, April 19, 1991).

The Dallas Area Rapid Transit's (DART) GIS was installed about 6 years ago when they were looking for a CADD system. Shortly after the installation, DART was producing "maps of minority population with census data without knowing this was GIS" (Alan Gorman, DART, telephone conversation with author, May 13, 1991). They state that GIS has benefitted DART in that they "can generate maps from their database management system (DBMS) in 15 minutes that used to take months" (Gorman, phone conversation, May 13, 1991). From other information gathered during the interview with DART's GIS design analyst, GIS has not only improved DART's efficiency and effectiveness in performing functions in the application areas mentioned earlier, but it is also being applied to rideshare matching and AVL. Further, DART's application in the area of facilities/land management handles not only fixed facilities and real estate, but deals with lease/license application, right-of-way acquisition, and proximity notification.

In other metropolitan areas, the MPO performs transit analysis and several other functions using GIS, in lieu of the transit agency. For instance, in Washington, D.C., the Metropolitan Washington Council of Governments (WashCOG) uses a variety of GIS software products to perform functions related to market analysis, whereas the Washington Metropolitan Area Transit Authority (WMATA) does not use GIS to perform transit analysis and does not plan to implement GIS in the future.

Another example is the Port Authority of Allegheny County (PAT) in Pittsburgh, which is currently working with the City of Pittsburgh and the County of Allegheny Planning Department. Specifically, they are contributing to a county pilot study, which includes a routing and service application.

The Nashville Metropolitan Transit Authority (MTA) was approached by Vanderbilt University to develop a custom GIS system. The first application under development is a customer information system, but eventually the MTA would like to perform other functions. This custom GIS is written in Turbo C and uses precensus Topologically Integrated Geographic Encoding and Referencing (TIGER) files (substantially edited by Vanderbilt) for the county representation. The program has "click-on" features, whereby, one can click-on an area to show bus routes, or click-on a route and show the schedule for that route.

The MPO in Portland, Oregon, Portland Metro, has a GIS but is primarily using a graphical transportation network modeling package for transit analysis, including corridor studies and light rail transit (LRT) studies. They would like better interaction between these two pieces of software, so they will be programming in-house to improve the interaction as projects demand.

In the San Francisco Bay area, two transit agencies are applying GIS to electoral redistricting. Alameda-Contra Costa Transit District is in the process of acquiring and implementing a GIS because of the redistricting. Bay Area Rapid Transit (BART) is considering the implementation of GIS, and one of the potential application areas is census-based redistricting in terms of demographics. In contrast, the Metropolitan Transportation Commission (MTC), an oversight agency covering nine Bay Area cities, is acquiring a GIS primarily because MTC wants to collect and maintain information on freeway call box locations, inventory, and usage.

In 1980, Seattle Metro was searching for a GIS to perform operations functions as well as planning functions. Since they could not find their desired functionality in commercially available products, they developed their own GIS, called TransGeo. TransGeo is being used for many applications in addition to the top five application areas mentioned previously:

- Ridematching (TransGeo is providing geocoded information to the ridematching system);
- Transit pass sales analysis; and
- Other applications, such as
  - Processing automatic passenger counter (APC) data,
  - Vehicle maintenance/mileage estimation,
  - Monitoring on-time performance, and
  - Peak load analysis.

Benefits to Seattle Metro are numerous. The company has obtained sophisticated, broad, and cohesive information from TransGeo. "A lot of people are now getting the same answer to the same question" (Jan Solga, Seattle Metro, telephone conversation with author, June 12, 1991). They are getting good Section 15 data without using a large staff, and shared information is enhancing the cooperation among various divisions. They are also getting good analysis outputs. For example, in a study on siting new park-and-ride lots, Seattle Metro was able to map the residence origins of users of existing lots by studying license plates. The company also has been able to evaluate custom bus routings for employers by analyzing residence and work locations and also has performed high-capacity planning by taking old and new schedules, obtaining schedule speeds, and plotting red and green bandwidths. In addition, it has exchanged vehicle volume information with the city for arterial planning.

At the San Diego Association of Governments (SANDAG), GIS has increased productivity and cost effectiveness in dealing with spatial data and has expanded capabilities in solving planning problems. SANDAG is using GIS for data collection from on-board surveys and facilities location. For public facility siting, it can better evaluate the consequences of particular sites before building.

In addition to transit analysis, GIS is being used in Southeast Michigan's Council of Governments (SEMCOG) for a variety of applications, including accident analysis, developing travel time contours from a point, examining changes in socioeconomic data, producing maps of origin and destination zones for motorists affected by changes, plotting traffic volumes and congestion, and displaying concentrations of variables such as elderly or handicapped persons. GIS has allowed SEMCOG to provide requested information to outside groups such as other cities, the state, consultants, and lawyers.

With the help of GIS, the Suburban Mobility Authority for Regional Transportation (SMART) in Detroit has been able to determine the best locations for bus shelters based on passenger boardings, to do visual queries by community, and to modify routes.

A comprehensive summary of current applications of GIS resulting from the interviews is shown in Table 2. A more

TABLE 2 CURRENT AND FUTURE APPLICATIONS OF GIS[1]

CURRENT APPLICATION AREAS	FUTURE APPLICATION AREAS
Transit ridership forecasting, service planning, market analysis	Transit ridership forecasting, service planning, market analysis
Map products design and publishing	Map products design and publishing
Fixed facilities and real estate management	Fixed facilities and real estate management
Telephone-based customer information services	Telephone-based customer information services
Transit scheduling and run-cutting	Land use applications
Ridematching (for carpools and vanpools)	Transit scheduling and run-cutting
Automatic vehicle location	Ridematching (for carpools and vanpools)
Transit pass sales	Automatic vehicle location
Police operations	Paratransit scheduling and dispatching
Paratransit scheduling and dispatching	Police operations
Rapid transit modifications	Traffic counts/projections
Improved transfer points and connections	Transit pass sales
Capital investment analysis	Fixed-route transit dispatching
Infrastructure management	Accident data retrieval and locations
Mode choice modeling	Bus/feeder bus service planning
Reverse commuter studies	Route planning
Corridor studies	Pavement management
Pavement management	Redistricting - demographic analysis
Freeway call box locations	Ridership counts
Traffic signals	Updates to route maps
Passenger counting for Section 15	Benefit assessment district processing
On-board survey data	Improved computer simulation (UTPS analysis)
Demographic profile	General displays
Transfer development rights	Evaluation of passenger counts
Revenue district tracking	Planning and customer service
Proximity notification	Route-level databases
Accidents	Buses per hour on streets
Travel time contours from a point	Bus schedules
On-time performance monitoring	Ferry users
Vehicle mileage calculating/estimating	Utility locations
	Affirmative action reports
	Inventory of stops
	Evaluating rights-of-way
	Incident management
	Remote image (raster) integration
	Heads-up digitizing
	Transit station impact analysis
	Capital planning
	Tracking regional development trends
	Census Analysis
	Route information
	Boarding locations
	Bus stop signs
	Dial-in/road call services
	Zoning

[1] Applications are listed in order of the largest number of agencies using GIS for the specific application to the least number of agencies using GIS for the specific application.

detailed summary of GIS applications by type of respondent (transit operator, MPO, and transit oversight agency) has been previously shown (*3*).

Future of GIS Implementation

The majority of organizations interviewed expressed an interest in implementing GIS, if they did not already have GIS, or in expanding the use of their existing GIS for other applications. An exhaustive list of areas for future implementation (Table 2) covered not only those application areas listed in the interview questions but also adjunct areas such as incident management, land use planning, traffic projection, and capital planning. The top five areas having potential for future implementation or expansion by transit agencies are

1. Facilities/land management (16), including
   —Fixed facilities and
   —Real estate;
2. Transit analysis (15), including
   —Transit ridership forecasting,
   —Service planning, and
   —Market analysis;
3. Design and publication of map products (12);
4. Telephone-based customer information services (12); and
5. Scheduling and dispatching for
   —Fixed-route transit (9) and
   —Paratransit (5).

For MPOs, the top five were slightly different:

1. Transit analysis (5), including
   —Transit ridership forecasting,
   —Service planning, and
   —Market analysis;
2. Design and publication of map products (4);
3. Ridematching (3);
4. Land use applications (3); and
5. Traffic counts/projections (2).

Comments of Transit Agencies and MPOs About Future Use of GIS

A number of comments were made by transit agencies and MPOs regarding their future use of GIS in transit planning. Baltimore's Mass Transit Administration (MTA) is considering GIS implementation to develop inputs to ridership projection and route-level planning. MTA needs to develop something more specific with a finer level of detail than its current transportation network modeling software. Currently, MTA is working with the University of Maryland to develop data bases for a GIS.

BART is considering GIS in the development of affirmative action reports, a disabled and minority population areas analysis report, to track utility locations, and for census-based redistricting. They are considering GIS implementation "to sharpen analytic capabilities for planning" (Aaron Weinstein, BART, telephone conversation with author, April 25, 1991).

The City of Des Moines Transportation Planning Commission is considering GIS implementation to perform market analysis of population and employment. The city would like to use TIGER files and to track building permits as a way of making future projections of employment and population.

In the Chicago area, several agencies are considering GIS. The Regional Transportation Authority (RTA) will be using their GIS for mode choice modeling, reverse commuter studies, and corridor studies. Metropolitan Rail's (Metra) primary use of their new GIS system will be evaluating new commuter rail corridors and analyzing current markets and performance.

The Chicago Transit Authority (CTA) is considering GIS implementation for planning and facilities management. In planning, CTA would like to collect data on boarding locations and ridership counts, to inventory bus stop signs, and to use census data to correlate visually with off counts. In facilities, CTA would like to integrate rail lines (power facilities, track, etc.) for display and evaluation of conditions, and to correlate facilities conditions with census and ridership data.

The Southern California Rapid Transit District (SCRTD) is going to use GIS for route planning, producing updates of route maps, benefit assessment, district processing, improving the customer information data base, improving computer simulations, and general display and evaluation of passenger counts.

The Port Authority of New York and New Jersey is considering expansion of their application areas to remote image (raster) integration, heads-up digitizing, customer information/transit information systems, transit station impact analysis (development impact analysis), and possibly capital planning. Engineering is interested in CADD aspects, capital improvement and design, tracking regional development trends, land use and suitability for development, facilities inventory and management, and census analysis.

PAT is planning on implementing a GIS to assist in service planning, transit scheduling, fixed facilities and real estate management, and incident management. PAT will implement the same GIS already in use at city and county planning agencies. PAT's reason for considering GIS implementation is "improved management and control" (Richard Feder, PAT, telephone conversation with author, 1991).

Factors in and Obstacles to GIS Implementation

The reasons for implementing GIS in transit agencies and MPOs are as varied as the number of organizations interviewed. Interview questions about benefits to the organization, problems encountered, and software selection together create a picture of why GIS is being used. Several factors contribute to future implementation or expansion, the most important of which are funding; resources and training; data issues; and outside organizational influences.

In particular, influences from outside organizations are strong, particularly when examining GIS use in transit agencies. More often than not, the selection of software and data by transit agencies is influenced by the experiences other local agencies have had with GIS. Also, the desire to be "compatible" with the software and data of other local agencies is strong, particularly when a cooperative group is formed to address GIS. These factors are analogous to those that were present during the introduction of microcomputer technology—organizations wanted to make educated decisions about purchasing hardware and software, which sometimes meant depending on the experience of other local organizations.

Beyond the aforementioned factors, other major obstacles to and factors in GIS implementation or expansion identified by specific agencies included

- Money required for hardware, software, and/or training;
- Lack of interdepartmental coordination and/or cooperation;
- Lack of recognition of GIS capabilities;
- Ignorance about the value of GIS technology;
- Coordination of data collection;
- Updating and maintenance of data;
- Lack of appropriate data;
- Effort required to input data;
- Unwillingness of other agencies to share data;
- Unwillingness to establish standards;
- Acquisition of base data;
- Development and calibration of models; and
- Interchange of data between other agencies.

MAJOR ISSUES ASSOCIATED WITH GIS USE

Major issues and problems associated with the implementation and use of GIS for transit planning cover those factors that make GIS successful or impede its success. These factors can be separated into (a) organizational structure and setting and (b) data integrity and management.

Organizational Structure and Setting

Two key issues—the GIS environment and the organizational commitment to GIS—affect how the organizational structure and setting influence the use of GIS. There is a wide variation in organizational structures as they relate to GIS use. Two internal organizational issues were evident from the investigation. First, within an organization, the GIS functions in either a centralized or decentralized environment. Examples of a centralized environment include DART and H-GAC, which have GIS departments. Also, in several organizations, the people trained in using GIS are in one department, rather than across several departments. Seven of the organizations interviewed have trained personnel in one department.

Most of the remaining organizations that have GIS are using it in multiple departments. For instance, the New York MTA "has introduced GIS informally because of the diversity of needs" (Carter Brown, New York MTA, telephone conversation with author, April 26, 1991). The approach has been to try to optimize data sharing and to persuade people to buy data-compatible software. In the future, planners at the MTA will have GIS in their job descriptions.

The identification of GIS in job descriptions shows a commitment to GIS. Beside DART and H-GAC, there are four other organizations that have personnel with GIS in their job descriptions.

Data Integrity and Management

In the investigation, several questions regarding data issues were asked. The issues covered were

- Data sources for street network;
- Time spent on data clean-up;
- Perception of data quality; and
- Types of transit system data available on computer.

In terms of data sources for local or regional street networks, the majority of organizations are using or are in the process of loading TIGER files from the 1990 U.S. Census. Fewer organizations are using Geographic Base File/Dual Independent Map Encoding (GBF/DIME) files from the 1980 U.S. Census and Digital Line Graphs (DLGs) from the U.S. Geological Survey. Only one organization, SANDAG, used a commercial data base (EtakMap®) as a primary data source but merged it with GBF/DIME data. Descriptions of these spatial data sources have been discussed previously (*3*).

In addition to these data sources, a few organizations were using locally developed data sources, including

- Urban Transportation Planning System network;
- Aerial maps;
- Locally developed sources based on enhanced TIGER and DIME data;
- Utility company data;
- Pavement management data; and
- Data from 911 program.

One example of a locally developed data source is from MassGIS, which is a cooperative organization of public agencies in Massachusetts run by the Executive Office of Environmental Affairs. MassGIS has not only developed a data base, much of which is based on DLGs, but it also has set standards on map scale and has coordinated data input from its members.

Another example is the Demographic Data Task Force in San Antonio. The purpose of this task force, which consists of the MPO, transportation agencies, utilities, and school districts, is to exchange mapping information rather than ask the task force members to change their data sources. Furthermore, an elected official is in charge of the Task Force, so there is political support for the group's efforts.

Organizations indicated that data clean-up and correction can be a significant effort. The amount of time required for data clean-up ranged from a few weeks to over two labor years per year. This wide range of effort is caused by such factors as the size of the area that the data represent, the accuracy of the source data in that region, and the application of the data in the GIS.

Perception of data quality varied as well, but the majority of organizations said that the quality was adequate. Obviously, after the completion of data clean-up/correction efforts, most interviewees have said that the quality was good. A few MPOs stated that the data quality was adequate for regional analysis but not for detailed local analysis.

GIS SOFTWARE PRODUCTS

The purpose of this section is to identify the software products that are in use for transit planning and to point out specific applications of the software in transit planning. In the investigation, a total of 16 software products were identified as being used by transit agencies and MPOs. Of those claiming to have GIS, 13 products were identified (Figure 2). The other three products are graphically enhanced transportation planning packages.

Description of Available Software

Almost 100 GIS and related software products are listed in *The 1990 GIS Sourcebook*, by GIS World, Inc. (*5*). These products cover many disciplines besides transportation, such as environment and natural resources, utilities, real estate, marketing, and agriculture. Although it is not exhaustive, the list of areas in which GIS has been applied represents major application areas. It would be impossible to review all GIS software products in this report, but it is important to review those products that are currently in use in transit planning.

GIS Software for Transit Planning

As stated previously, 13 GIS products are in use for transit planning by the organizations interviewed. Ten of these products are commercially available (Pinnacle is a custom-designed system being used by SMART, SEMSAS is a system developed in-house for SEMCOG, and TransGeo is a system developed in-house for Seattle Metro). The companies associated with these commercial products, along with the transit agencies and MPOs that use them, the computers they work on, their interface to DBMS, and other pertinent information are shown in Table 3. All of the packages listed in this table are classified as GIS because they all claim to have some topological functions (*5*). No independent verification of these claims has been made by this study.

Of the commercially available GIS products, TransCAD is the only one that contains specific transportation planning functions relating to the four-step planning process. Most transit agencies and MPOs that are doing planning are still using transportation planning packages in addition to a GIS.

There is a distinct difference between GIS data functions, such as data extraction from overlays, and network analysis capability, which is an important feature of GIS used specifically for transit planning purposes. A number of packages listed in Table 3 claim to have network analysis capabilities, which are essential for routing analysis and service planning where routes are displayed and plotted. Detailed descriptions of the successful use of each GIS by particular agencies have been described previously (*3*).

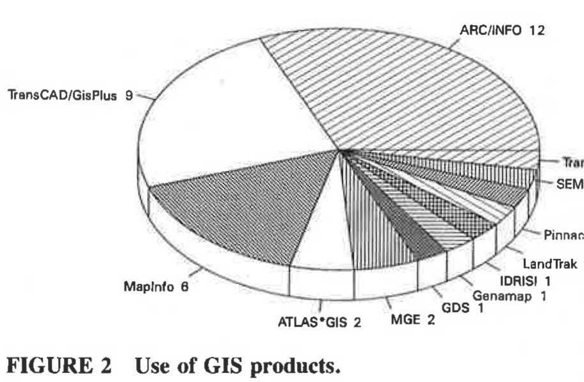


FIGURE 2 Use of GIS products.

Interfaces with Other Planning Tools

A number of existing packages perform traditional transportation planning functions. The investigation showed that several agencies are using these packages in addition to GIS. These packages include FTA's public domain UTPS and the commercial products EMME/2, MINUTP, and TRANPLAN.

Since the interview questions did not concentrate on the use of these products, a significant amount of information is not available on the specific use of these products. However, all of these packages, as well as TransCAD, have similar capabilities with respect to transportation planning functions. They all have capabilities in network building and editing, trip generation, trip distribution, modal split, and network assignment (traffic and transit). They also provide graphic displays and plotting and general output capabilities.

The subject of GIS integration with other planning tools, specifically those transportation planning packages mentioned above, was identified as an issue during the interviews. Where planning tools and GIS are being used, they tend to be used separately. For instance, in the Atlanta Regional Commission (ARC), the MPO for the Atlanta region, TRANPLAN is being used for transportation planning, and ARC/INFO is being used elsewhere in ARC. Now that it has been exposed to ARC/INFO, the transportation planning group would like to integrate TRANPLAN and ARC/INFO.

Tampa Urban Area MPO wishes to integrate the Florida Standard Urban Transportation Modeling Structure (which merges land use and transportation data) with their GIS, Genamap, to produce graphics. Tampa also has two other transportation planning packages. The mainframe package is UTPS and the PC package is TRANPLAN.

Portland Metro (MPO for Portland, Oreg.) has used ARC/INFO to examine land ownership adjacent to the LRT line. However, Portland is currently using EMME/2 for transportation modeling and has expressed an interest in integrating both of these packages by developing interaction routines.

WashCOG is using PC ARC/INFO, Gis Plus, and MINUTP (it is also evaluating a raster-based GIS, SPANS). WashCOG has successfully integrated data bases and plans to use ARC/INFO as a data base builder and a front end.

CONCLUSIONS AND RECOMMENDATIONS

Three major conclusions can be derived from the results of this investigation. First, the transit agencies and MPOs interviewed clearly have an understanding of what GIS is. However, in several cases, the relationship between GIS and transit planning may not be as clearly understood, particularly for organizations that are considering GIS implementation for a variety of applications beyond typical transit planning functions. These functions may include

- Operations; including
  —Scheduling, run-cutting, and dispatching (these operational functions might include Americans with Disabilities Act paratransit service area determination) and
  —AVL;
- Planning, including
  —Ridership forecasting,

—Service planning/modification,
—Market analysis, and
—Transit and land use development review analysis;
- Marketing, including
  —Market/demographic analysis,
  —Customer information services, and
  —Transit pass programs;
- Facilities inventory and management;
- Real estate inventory and management;
- Maintenance, including
  —Right-of-way,
  —Vehicles, and
  —Stations; and
- Engineering.

Second, the selection of GIS software to perform transit planning functions seems to be based on several factors, including

- Funding,
- Resources,
- Compatibility with other local organizations, and
- Capability to perform transit planning functions.

TABLE 3 COMMERCIAL GIS PRODUCTS USED IN TRANSIT PLANNING[1] (5)

SYSTEM NAME	COMPANY	USERS	COMPUTERS	DBMS INTERFACES	MEASUREMENTS (Proximity Analysis and Area Measurement)	GENERATE BUFFERS (Around Points, Lines and Polygons)	POLYGON OPERATIONS (Point in Polygon, Line in Polygon, and Polygon Overlay)	NETWORK
ARC/INFO	ESRI	ARC, Bi-State, CTPS, H-GAC, Houston Metro, MAPC, Miami MPO, Port Authority of NY & NJ, Portland Metro, SANDAG, SCRTD, WashCOG	Workstations and PC-DOS	INFO, ORACLE, INGRES, Sybase, INFORMIX, DB2, Rdb, SQL, DS, dBASE III & IV	●	●	●	●
ATLAS*GIS	Strategic Mapping, Inc.	Houston Metro, Metra	PC-DOS	dBASE III and compatible	S[2]	S	S	
GDS	McDonnell Douglas	DART	Workstations	Any SQL-based database	●	●	●	●
Genamap	Genasys II, Inc.	Tampa Urban Area MPO	Workstations and PC-DOS	INGRES, ORACLE, INFORMIX, HP ALLBASE, SQL 400, DB2	●	●	●	●
GisPlus, TransCAD	Caliper Corporation	NOACA, WashCOG, Baltimore MTA, LIRR, NJT, NYCTA, NYMTA, Port Authority of NY & NJ, Chicago RTA	PC-DOS	Lotus 1-2-3, Generic with ASCII export capability	●	●	●	●
IDRISI	Clark University, Graduate School of Geography	RVTD	PC-DOS	dBASE III, Professional File	●	●	●	●
LandTrak	GeoBased Systems	City of Phoenix Public Transit	PC-DOS	Proprietary database	S	S	S	●
MapInfo	MapInfo Corp.	Houston Metro, MARC, Bay Area MTC, Omaha-Council Bluffs MPO, PSCOG, TTD	PC-DOS	dBASE, FoxBase, ASCII	●	S	●	
MGE	Intergraph Corporation	DVRPC, NYCTA	Intergraph UNIX Workstations	ORACLE, INGRES, INFORMIX, DB2	●	●	●	●

[1] A portion of the information in this table is from GIS World, Inc., ***The 1990 GIS SOURCEBOOK***, pages 20-37.

[2] "S" indicates that the software does not have full functional capability in this area, based on summary information from the ***1990 GIS SOURCEBOOK***.

The last factor, capability to perform transit planning functions, is not usually weighed as heavily as the other factors.

It is important that the selection process involve a balanced examination of all these factors in relation to the specific transit analysis needs of the organization. Thus, the following issues in software procurement and implementation should be considered:

- Performing a GIS needs analysis, including matching the "needed" analysis tools with available products;
- Procuring the appropriate software and hardware; and
- Developing an organizational structure or modifying an existing structure to effectively implement GIS technology.

Third, given the importance of using spatial data in GIS, and given the inconsistent nature of these data, the following data processes should be closely examined before software implementation, including

- Data acquisition;
- Data integrity and maintenance, which require local and/or regional coordination and communication similar to the federal interagency activities within the Federal Geographic Data Committee; and
- Other data issues, such as appropriate scales for certain data and data use, which require local understanding and agreement.

Fourth, the information currently available on GIS software comes from the vendors. Thus, a more objective evaluation of functionality is needed, specifically oriented toward transit applications. The following factors describing commercially available GIS products should be evaluated before selection:

- Typical transportation planning functional capabilities;
- Hardware requirements;
- Data base capabilities/interfaces;
- Geographic/topological capabilities; and
- Output capabilities.

In conclusion, at the federal level, the integration of land use and transportation policy and planning is critically important in addressing mobility in metropolitan areas. GIS is the tool that is capable of examining this relationship and providing a decision support mechanism for developing policies and programs based on that relationship.

ACKNOWLEDGMENTS

The research presented in this paper was sponsored by the Department of Transportation's Research and Special Programs Administration, John A. Volpe National Transportation Systems Center. The author thanks Bruce D. Spear of the Volpe National Transportation Systems Center, for his guidance and assistance in performing the research. The author also acknowledges Deanna Mirsky of EG&G Dynatrend, Inc., for her effort in performing the telephone interviews, and Robert W. E. Antonisse of GIS/Trans, Ltd., for his work in drafting the initial set of questions and assisting in a review of those questions.

REFERENCES

1. *Understanding GIS—The ARC/INFO Method.* Environmental Systems Research Institute, Inc., Redlands, Calif., 1990.
2. W. E. Huxhold. *An Introduction to Urban Geographic Information Systems.* Oxford University Press, New York, 1991.
3. C. L. Schweiger. *Current Use of Geographic Information Systems.* Report DOT-T-92-02. FTA, U.S. Department of Transportation, 1992.
4. D. H. Pickrell. *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Costs.* Report DOT-T-91-04. FTA, U.S. Department of Transportation, 1990.
5. *1990 GIS Sourcebook.* GIS World, Inc., Fort Collins, Colo., 1990.

Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Transit-Based Approach to Land Use Design

EDWARD BEIMBORN, HARVEY RABINOWITZ, CHARLES MROTEK, PETER GUGLIOTTA, AND SHUMING YAN

The nature of land use patterns that are sensitive to the needs of public transit was examined. Design elements that directly address the success of development activities and transit services are proposed; requirements for successful transit are discussed; and design guidelines for land use, access systems, and transit service types through a range of scales are provided. Transit-sensitive land use design can be developed through the designation of transit corridor districts (TCDs) that would separate transit- and auto-oriented land uses. Such areas would have a mix of land uses, with higher densities located near a transit route. A high-quality access system for pedestrians and bicyclists should be provided to permit easy connections between buildings and transit vehicles. Guidelines are developed for the overall administrative and policy issues, systems planning considerations, and specific designs of individual districts in which transit service is provided. A prototype TCD, based on the guidelines, illustrates how the guidelines can be applied at a specific location.

In the last 50 years, suburban areas have evolved into places having a unique life-style and pattern. Widespread availability of automobiles and the mobility they provide has led to a dispersal of activities and trip making. Employment and commercial activity have grown along with housing and recreation to lead to complicated trip patterns and increasing congestion of local streets and arterials. Activity centers and trip generators are poorly tied to each other and totally depend on the automobile for access. Little, if any, concern has been made for pedestrian or bicycle movement or for the provision of public transit in land use decisions. Most work on the problem of transit in suburban areas to date has concentrated on the development of new methods of operation or administration of public transit services in suburban areas. Demonstration projects have been attempted and new services have been offered with the hope of finding a "magic" transit solution to suburban travel problems. Although these efforts certainly have merit, they tend to ignore the underlying land use planning and design issues that are the root of many of these problems.

Recent efforts to rethink suburban land use provide new directions for suburban planning and design (*1*). Early work by Teska (*2,3*) defined a concept of high-accessibility corridors that would integrate highway, transit, and land use development. Beginning in the early 1980s, proposals for innovative physical design solutions to address suburban problems in high growth areas were initiated. These included development of the Neo-traditional Neighborhood Design concept led by the architectural firm of Duany/Plater-Zyberk (*4*) and the Pedestrian Pocket/transit-oriented development concepts as advanced by Calthorpe and Associates (*5*). Both of these concepts move toward higher density, mixed-use development with an emphasis on pedestrian movement. By the late 1980s, a few developments based on these solutions were under construction. Many of these developments reflect projects done 50 or even 100 years earlier. These precedents included a pedestrian-oriented environment, conservation of the landscape, significant amenities, and higher densities, and often provided mass-transit opportunities as well. Innovative solutions for suburban development have found acceptance by the development community in areas in which suburban problems are most intense. Although it is too early to judge the acceptance of these pioneering projects by market response (the first projects are still under construction), conditions indicate that they may be successful and such solutions may proliferate. At the same time, efforts in the Pacific Northwest by Snohomish County Transportation Authority (SNOTRAN) (*6*) and the Seattle Transit agency (*7*) and in Canada (*8*) have provided a better definition of how public transit can relate to development activities. Collectively these efforts can lead to a model that integrates land use and transit services and a movement away from the auto-dependent suburbs.

This paper provides an outline for a land use planning, design, and development process that is sensitive to the operational and economic requirements of public transit systems. The goal is to develop a transit basis for land use design and to demonstrate how planning decisions could be made to provide a greater variety of modal options for suburban communities. This paper condenses a larger work (*9*) that provides comprehensive guidelines for transit-sensitive suburban land use design.

PRINCIPLES

Elements of Successful Transit

To look at a land use design from a transit perspective requires a clear understanding of what is necessary for transit to successfully compete with the automobile in terms of access, convenience, and comfort. A land use pattern based on transit should incorporate the following principles:

1. *Market orientation.* Transit services should be operated from a market-based, user-oriented point of view. The driving force in decisions regarding the planning, location, design,

E. Beimborn, Center for Urban Transportation Studies and Department of Civil Engineering and Mechanics, University of Wisconsin, Milwaukee, Wis. 53201. H. Rabinowitz, School of Architecture and Urban Planning, University of Wisconsin, Milwaukee, Wis. 53201. C. Mrotek, Hammel Green Abrahamson Architects, Milwaukee, Wis. 53203. P. Gugliotta, Village of Carol Stream, Carol Stream, Ill. 60193. S. Yan, Ohio-Kentucky-Indiana Regional Council of Governments, Cincinnati, Ohio 45203.

frequency, operation, and maintenance of public transit and associated land uses should be to respond to customer needs. Transit can be successful in attracting a significant number of users from the automobile if it provides a user-oriented service. User-oriented transit operates directly between passengers' origins and destinations without transfer, on a convenient schedule, and at a price that is competitive with the automobile. Transit stops and building entrances should be located to minimize walking and there should be clear pathways that connect activity centers and transit services. Under such conditions, and with the use of appropriate land use patterns, transit will be successful and provide a meaningful alternative to the automobile.

2. *Land use pattern with concentrated trip ends.* Transit requires an adequate market size to be successful. There needs to be a concentration of trip ends along the transit service. Those activities that most relate to transit should be located as closely as possible to transit stops. Furthermore, they should be concentrated to create a number of high-volume destinations to support a high level of transit service.

3. *Quality access system.* Access to public transit by pedestrians, bicyclists, and automobile users should be convenient, safe, and direct. All transit trips begin as pedestrian trips and end as pedestrian trips. Pathways should be provided that minimize walking distances to points of activity, provide an interesting bicycling and walking experience, provide attractive waiting environments, and incorporate land uses and services that support pedestrians and bicyclists.

4. *Transit-oriented streets.* Street systems should be laid out to facilitate efficient transit operations. Streets that have transit service should be free of sharp curves or steep grades, and through routing should be provided. Transit service should directly connect activity centers; there should be no need for shuttle services that connect activity centers to primary transit lines. Geometric design criteria for transit routing should provide for high-speed movement, adequate stopping areas, safe pedestrian crossings, and proper visibility. Automobile traffic should be restricted if necessary, to ensure that transit vehicles do not experience delays because of highway congestion.

Conceptual Design

A major goal of this project was to develop a conceptual framework for the design of transit-sensitive suburban areas. This effort was based on our reviews of the literature and an analysis of exemplary designs as outlined in *The New Suburb* report (*1*). Though none of the designs we examined incorporates all the elements of a transit-sensitive suburb, taken together they provide a variety of concepts and features that could be the basis for such projects. The integration of transit and land use planning should provide the features and services necessary to create a genuine and workable community. The suburban community must be planned to be an attractive and viable place to live and work as well as capable of confronting issues related to the provision of transit. The land use plan should have at its core a mix of uses and a pedestrian orientation. In addition, the location of streets and parking should support transit services. Part of the land use plan is the preservation of land in natural and agricultural areas that will also reinforce the milieu of the developments.

The project must function as a community. The design should provide features, amenities, design, and services that will make the community an attractive place to live in. Market considerations also include the provision of many types of housing to attract a diverse market, as well as a market that will use transit more frequently. Transit services should be market oriented (i.e., the needs of users should be the driving force in its design and operation).

Based on these factors, a conceptual design was developed that separates transit- and auto-oriented land uses and calls for the creation of transit corridor districts (TCDs) where public transit, walking, and bicycles are to play a major role in providing mobility. Transit corridor districts would serve as prime locations of transit-oriented land uses and as a means of creating an environment in which mobility is provided by non-automotive means (Figure 1). Transit corridor districts would be segments of existing arterial streets but ideally would be separated from arterial highway corridors by a distance of at least 1/4 to 1/2 mi. These corridors would be protected through zoning actions and by the careful placement of periodic closures to nontransit traffic—to avoid excessive automobile usage (Figure 2). Technological flexibility should be provided in the design of transit corridor districts. Corridors for transit would likely be serviced by buses at early stages of development, but they should be designed to be easily upgraded to light rail transit or other technological options in the future. The critical feature is that there is a concentrated land use pattern and pedestrian/bicycle access system that supports and is served by transit.

Separation of transit service from conventional auto-oriented arterials is attractive since conventional arterials in the suburbs are seldom suited to transit service (Figure 3). Suburban arterials are typically lined with strip commercial developments that are normally set far back from the roadway and have few, if any, pedestrian facilities that can connect them to transit. Land uses along suburban arterials are also often

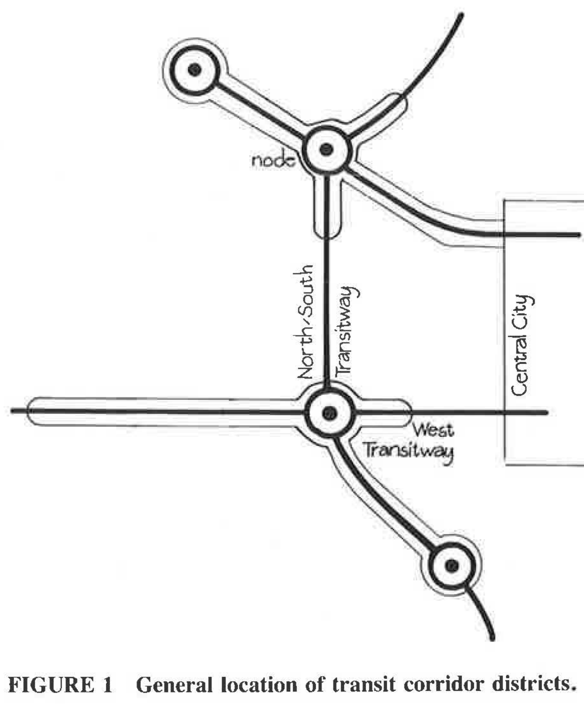


FIGURE 1 General location of transit corridor districts.

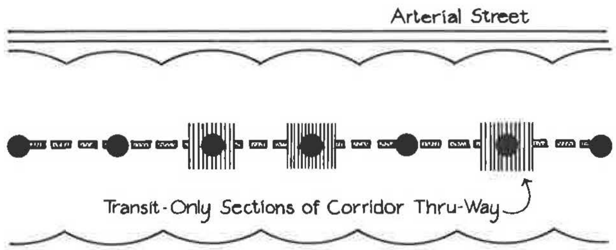


FIGURE 2 Control of through auto traffic.

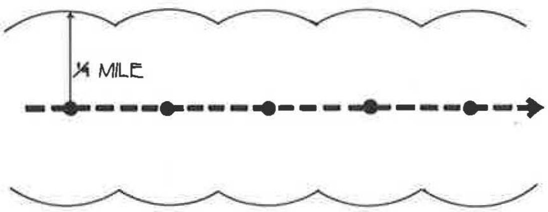


FIGURE 3 Separation of auto- and transit-oriented land uses. Auto-oriented land uses are kept near arterial to maintain pedestrian movement at the transit corridor.

inappropriate for transit use. Auto-oriented uses such as lumber yards, garden centers, drive-in banks, auto dealers, fast food drive-through restaurants, and funeral homes, which predominate along suburban arterials, are intermixed with land uses that relate to transit. On the other hand, those land uses that relate strongly to transit, such as housing, office buildings, educational facilities, retail buildings, and factories are often separated from the arterials that have the transit service. Thus the separation of transit corridors from highway/arterial routes and the location of land uses appropriate to each of these modes can create a more efficient and convenient overall system (Figure 4).

Part of the transit corridor district zoning would designate locations for activity centers where stops would be located. These centers, which would allow a variety of uses and high levels of activity, would be the focus of individual neighborhoods, as developed by various organizations. This type of zoning creates an attractive community as well as a feasible public transit system.

These designated transit corridor districts will capture much of the metropolitan growth for some time. Areas between districts will either be preserved as agricultural and natural areas or will contain low-density uses. The use of only a portion of the land surrounding the central city for development encourages preservation of the environmental quality of open and rural spaces.

GUIDELINES

Our basic approach was to define a development pattern that follows corridors and occurs as linear extensions of urbanized areas. Transit routes will operate most effectively in a linear pattern with very few turns. These overlapping demands of market forces and transit service needs provide a natural situation for the development of organized transit corridors.

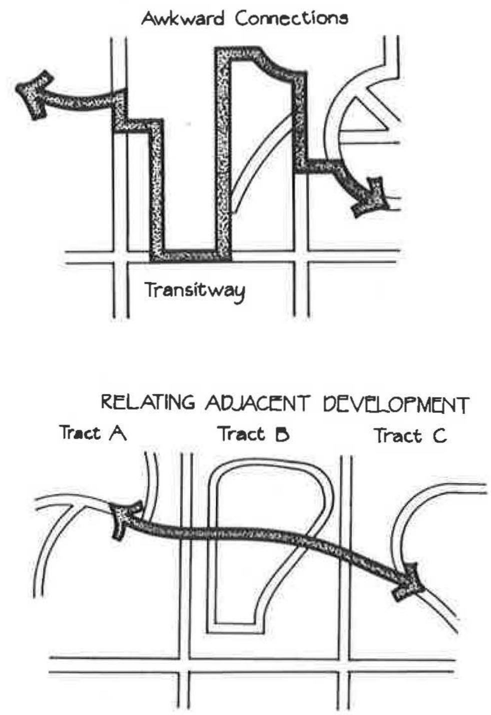


FIGURE 4 Provision of direct routing between parcels.

Three major guideline categories were developed: (a) administration and policy guidelines; (b) systems planning guidelines; and (c) guidelines related to the design of the transit corridor districts. The systems planning and district planning guidelines each have three parts: land use, access to transit, and transit operations guidelines. Policy guidelines relate to how things are implemented, who has input into the process, and how services and areas are managed. Systems planning refers to the overall location of transit corridor districts, access to public transit, and general rules for the operation of transit services. District level relates to the way in which land uses are arranged within a transit corridor district, how access is provided, and how transit services are accommodated.

Space does not permit a discussion of all of these guidelines. However, certain key guidelines were developed to help explain the concepts. In addition, a prototype design was developed to help illustrate the concepts involved.

Separate Transit-Oriented and Auto-Oriented Land Uses

A key element in the design of transit-sensitive suburban land uses is to spatially separate activities that are highly related to the automobile from those that are related to public transit. Certain activities are distinctly auto-dependent—it is difficult to perform them using transit. These are activities that require transporting large objects, that require multiple stops, or that take place in evenings or on weekends. Examples include purchases at a lumberyard, collecting a group of children and taking them to a soccer practice, or going out for dinner and a movie. Activities conducive to the use of public transit include those that occur with some regularity and with a direct origin-destination pattern.

To maximize the potential for the use of public transit and to alleviate suburban traffic problems, there should be a separation of land uses based on their associated traffic modes. Ideally, parallel corridors would be developed, one primarily for the automobile and its associated land uses, and one for transit and its related land uses. Land uses oriented to the automobile—car dealers, large-package retail shopping, low-density housing, motels, car-oriented food franchises, large-plot outdoor recreation, etc.—should be located along highway corridors. Land uses oriented to transit—high-density residential developments, office buildings, schools, facilities for the elderly, and some retail—should be located along a transit corridor. Within the corridor, a mixture of building types and the proximity of building types would also encourage pedestrian access. Concentrated locations of educational facilities, office buildings, shopping, and housing would reduce the amount of transportation required—whether by auto or public transit (*1,6*).

Encourage Transit-Sensitive Land Use Design by Designating TCDs

The local zoning ordinance is the primary tool used to implement land use policy. Unfortunately transit issues are seldom addressed in contemporary zoning ordinances. The local zoning ordinance should be updated to include the consideration of transit throughout all relevant sections. The inclusion of transit will provide a regulatory basis for the enforcement of a transit-based land use pattern. Detailed transit regulations should be incorporated into the zoning code for transit corridor districts as an overlay zoning area.

Additions to the existing zoning ordinance will improve a municipality's efforts to encourage transit and to concentrate development in areas with a potential for high transit use. A TCD would permit much greater regulation of transit-related concerns in primary service areas while allowing the conventional zoning code to govern development in other areas.

The review process for proposed projects in a TCD would be much like the review process for planned unit developments. The TCD would expand on the concept of a transit overlay zone, used in the Portland, Oreg., area that focuses on the mixture and density of developments near light rail stations (*6,7*). Transit districts of 10 to 11 acres in size were created at light rail stations for high-density residential and office development. Another example of a zoning district would be the many historic districts created to preserve the history of older downtowns. Transit corridor districts could be areas along existing arterial streets or could be future sites of new roadways/corridors.

Predesignate a Future System of Transit Corridors

A transit-sensitive solution to land use in the suburbs must be part of an overall metropolitan or regional transportation plan. A transportation corridor must be linked to heavily concentrated locations, such as the central business district or existing major employment areas and suburban activity centers.

An important element in making the concept feasible is to predesignate corridors for transit service and for the location of transit-oriented land uses. It is vital to establish the basic transit corridor district locations before most development activity. The most effective corridors will be initiated in undeveloped areas. Early location and designation of the corridors is essential to making subsequent land use decisions with a commitment to future transportation services. Early establishment of TCDs also reflects a commitment from the government to future developers that a full-service transit line will operate in a specific area, which helps to eliminate fear and speculation about the future of the corridor. Demand for land along the corridor should stabilize once the zoning is established. This will enable communities to separate auto-oriented land uses from transit-oriented land uses and to locate them according to the appropriate means of transportation.

The creation of transit-sensitive districts ideally can be accomplished by a physical separation of transit services from primary auto-oriented arterials. Transit services should be at least 1/4 mi away from the parallel arterial and should provide opportunities, through zoning, for development of land uses, population sizes, and densities that relate to transit. The success of the corridor relies on the ability to integrate a pattern of land uses that is compatible with transit, as well as with the internal design of each site.

Provide Adequate Population Size and Density to Support Transit Use

The density of trip ends at a transit stop is critical in determining if public transit has sufficient demand to justify its service. Both land use densities and the total population in the service area of a stop are important. Suburban areas have many areas with higher densities that could relate to transit, but they are physically separated and difficult to connect. TCDs provide a way to organize such areas that can be served by transit. Average residential densities of at least seven dwelling units per acre within the service area of a route are considered the minimum level to justify the use of local bus routes with 30-min headways, whereas densities of 15 dwelling units per acre are needed for 10-min headways (*7,10*). These values, however, can vary significantly based on assumptions about capture rates of transit, service frequency, average fares, subsidy rates, hours of operation, speeds, and average hourly costs. The critical factors that lead to density requirements are the capture rate, the cost recovery ratio, and the service ratio of transit (*9*).

The required density of residential or employment land use depends on assumptions about the portion of trips that use transit and trip rates per household. An important tradeoff occurs between these factors. Whereas a high density is required if there is a low capture rate by transit, a lower density is needed if the capture rate is higher. The density requirements drop off rapidly if transit successfully captures market share. On the other hand, a high capture rate is likely the result if there are low fares and high levels of service. These in turn increase the need for higher densities.

Density requirements also vary directly with service frequency and farebox recovery rates. If high levels of service are provided, there will be a need for higher densities. Analysis of these factors indicates that the required residential and employment densities for transit are complex and strongly dependent on policy (i.e., subsidy rates and fares), as well as operational factors (i.e., hours of service, headways, and hourly cost of operation). It is important that these factors be explicitly considered in land use design to ensure an adequate market for transit services.

Encourage Technological and Infrastructure Flexibility

A transit corridor must be able to accommodate various transit modes. It is expected that the transit corridor would initially be used by buses and perhaps even minibuses; however, the corridor should be designed to provide options for other technologies. As the market size increases, more capital-intensive modes, such as light rail, become feasible. Thus alignment and placement of underground utilities should permit an upgrading to light rail transit in the future if warranted. Geometric design of transitway components of the corridor should be based on the needs of a rail system rather than a bus system including more stringent standards for gradient and curvature. The corridor could be used by a mixture of road-based vehicles and services such as a conventional buses, vehicles for the disabled, express services, shuttles, subscription buses, taxis, and van pools.

Control Through Automobile Traffic

The provision of a convenient transit service requires a speed and level of service competitive with those of automobile travel. If transit vehicles operate along a congested street, travel times by transit will be increased and the street will be dominated by auto traffic. Because TCDs are areas of concentrated development that generate significant numbers of trips, it is important to control through automobile traffic to prevent excessive congestion. One way would be to provide periodic sections in the transit right-of-way where only transit vehicles would be permitted. These breaks would occur approximately at every mile and would likely be located at high-activity stops. The remainder of the corridor would operate with mixed traffic, with the roadway serving as a local or collector street.

Use Corridor for Primary Pedestrian, Bicycle, and Transit Movement

The corridor should be designed to accommodate pedestrian and bicycle movement as well as transit vehicles. Separate pathways should be provided parallel to the transit routes. These pathways should be on both sides of the roadway and should accommodate two-way movement. In addition, direct pathways should be provided to lead pedestrians safely and directly to the transit stops. High-quality pedestrian/bicycle facilities are essential for bringing users to and from the transit system, to interconnect areas, and to improve the overall quality of the environment in the corridor.

The designation and location of transit stops are key decisions in the planning process for a transit corridor district. Because pedestrian use of transit falls off rapidly when offices or residences are located more than 1/4 mi from a stop, to provide good quality pedestrian access, stops should be spaced no more than 1/4 mi apart. This distance provides a maximum walking distance of 1/8 mi for trips beginning or ending on the corridor itself and a band width 1/2 mi wide for concentrated land use related to transit. The overall pattern is a series of overlapping concentric circles that define the zone of transit-oriented land uses. These areas (*stadtwurst* or sausage city) may be separated by areas of open space where stops are omitted. In areas of concentrated demand, stops could be located more closely together, as close as 1/8 mi to improve accessibility.

Reduce Noise and Air Pollution Levels of Transit Vehicles

Transit vehicles, especially buses, have a poor image in suburban areas (*11*). Local residents will often protest the location of bus routes in their neighborhoods because of the noise and air pollution produced by the vehicles. To prevent negative reactions to transit services, present noise levels of buses (in the range of 80 to 85 dbA while pulling out from a stop) would need to be significantly reduced. Similarly, vehicle emissions of pollutants and visible exhaust need to be reduced. Transit service in the corridor district must be of a high quality to both attract patrons and not be a nuisance in the community. Efforts to design cleaner, quieter, and higher-quality vehicles are critical to the development of the overall concept.

Provide Mixed Land Uses

Traditional suburban zoning can be characterized by a separation of land uses, such as residential, commercial, educational, and recreational land uses, requiring the use of the car and many separate trips. By locating various land uses in close proximity, two benefits can be achieved. First, the total number and length of vehicle trips within the area could be reduced. It would not be necessary to travel to numerous locations because most destinations would be within a few minutes' walking distance of each other.

The second advantage of mixed-use activities and land use is the improved feasibility of transit service. Transit operates best when there are simple origins and destinations and when users can meet their needs by walking to the destination of the trip. Generally, suburban residents do not use transit because they need to make trips to multiple locations during the day. If these activities and destinations can be concentrated, the auto's advantage over transit will be greatly reduced (*5,6*).

Land uses should be arranged to maximize the potential for walking and bicycle trips as well as for use of transit. A mixture of activities, including housing, employment, shopping, public facilities, and schools is desirable around each transit stop. Densities would be highest near the stop and then remain fairly high within the 1/4-mi walking distance of transit.

Relate Design and Connections of Adjacent Developments Across "Seams"

The incremental planning and development of suburban subdivisions and parcels result in an unrelated functional and visual environment between tracts (*6*). These mismatched "seams" can be avoided in a master planned district. During site planning, each land development parcel should be required to include access points to neighboring tracts. The coordination of these seams and connections should be strictly regulated by the district. Considerable flexibility can be allowed within parcels as long as proper connections are maintained to the adjacent parcels.

Minimize Distances Between Building Entrances and Transit Stops; Provide Logical Connections Between Buildings and Transit

Nearly all trips begin in a building and end in a building. To maximize the potential for transit, building entrances and transit stops should be located in close proximity to each other. Moreover, there should be a clear, direct path between the building and transit stop locations. Although it may seem obvious, this point is seldom taken into consideration in conventional suburban development. Transit stops usually are located on arterials, and it is necessary to walk considerable distances through parking lots and across grassy areas to get to a building. Pedestrian walking distances should be measured along the actual paths, not just straight line distances.

There are various ways to provide good access to buildings, especially in the site design phase of development. For example, buildings and their entrances could be directly located next to transit stops, which could mean locating parking or open space behind or beside a building rather than in front of it. In addition, buildings themselves could be set perpendicular to the transit corridor rather than parallel to it.

PROTOTYPE DESIGN

To test our guidelines and concepts, a prototype design of a transit-based land use pattern was developed for a suburban area. The site chosen is 1/2 mi wide by 2 mi long and is located west of Milwaukee in the township of Menomonee Falls. The area is rural in character with little development. However, urban development activity is occurring south, north, and east of the site, and it is likely that it will see a transition from rural to suburban land use in the near future. The site lies between two suburban centers that have had substantial suburban development during the past 20 years. To the east is an industrial district and the city of Milwaukee, and to the west are other rapidly growing areas. The site chosen is parallel to a major east-west arterial that connects to the U.S. Highway 45 belt freeway 2.5 mi east. The comparable arterials located to the south have been sites of substantial commercial strip development.

The site consists of gently rolling hills with no significant slopes to impede development. Current use is agricultural with a few scattered residences. A large wetland is located in the northwest corner of the site. There are some wooded areas in the site, primarily in the form of mature fence rows with some larger wooded tracts in the south-central and west portions of the site. Land ownership is primarily in large parcels up to 80 acres in size.

The selection of this site was based on its potential for future suburban development activity. In addition, it appeared to be a potential location of transit services that could connect into the Milwaukee central area and provide an east-west crosstown service into the city of Milwaukee. Because the site is relatively undeveloped and has relatively few owners, there are opportunities to provide concentrations of demand that could create a significant market for transit services.

Transit Service

It was assumed that there would be two transit routes that would intersect in the district. An east-west line that parallels Silver Spring Drive and a north-south route that connects the suburban centers of Menomonee Falls and Brookfield Square. Our primary emphasis is on the east-west line, which could be extended westward an additional 2 mi before it would encounter existing development and have to be rerouted along Silver Spring Drive. The intersection of the two routes presented an opportunity to create a town center for shopping and office activity built around the transit services. Since no substantial shopping districts existed nearby the town center appeared to be a logical use that would work well with the transit service.

Transit stops were located approximately every 1/4 mi along the corridors with a closer spacing in the town center. Generally stops were located 1/8 mi in from crossing arterials to provide for reduced walking distances to transit. Some modifications of stop locations were made to take advantage of site conditions.

Design

The prototype design (Figure 5) was developed by a team of architectural faculty and students following the guidelines developed for this project. Four districts were identified as a basis for design. These areas—the Woods, the Farms, the Central District, and the Estates Area—were identified based on existing land use or the impact of the transit system on design or both. These themes helped to develop a basis for design, they also help to illustrate how various approaches can be blended within a transit corridor district and to examine how the guidelines would be used by various designers working on five sites with varying topography and other natural features such as woods, lakes, and wetlands.

In general, the design includes a band of high-density housing and office facilities located along the east-west transit route and a lower density development at the fringes. A business district/civic center is located at the point of intersection of the two transit routes toward the east end of the site.

Smaller neighborhood business areas are located at other transit stops to the west. The plan would contain approxi-

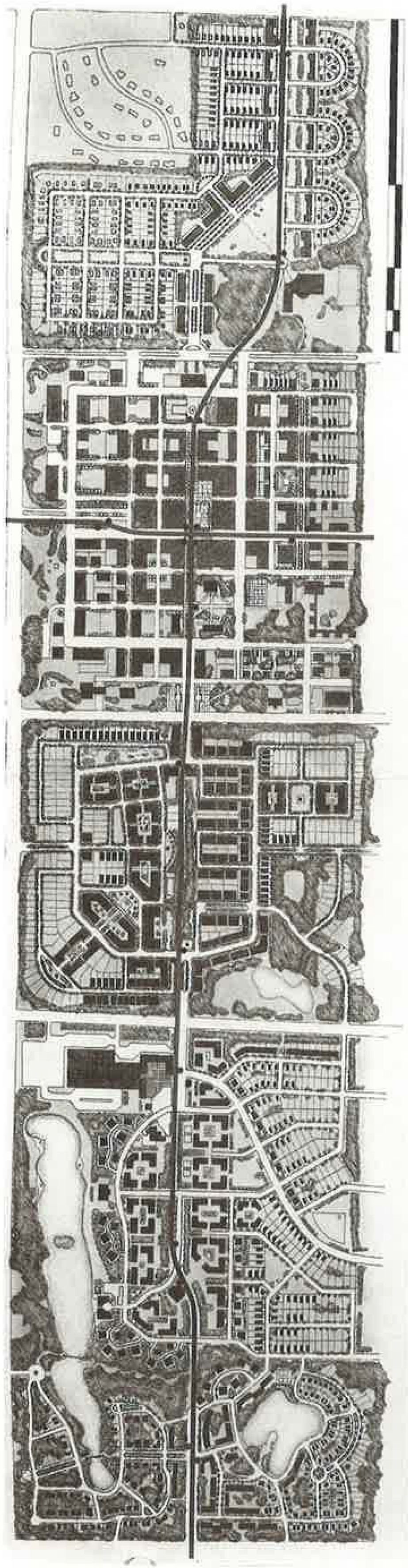


FIGURE 5 Prototype design.

mately 3,000 housing units and approximately 1.4 million ft^2 of commercial/office space. Substantial retail areas also would be included which would result in a net residential density of approximately 6.5 units per acre for residential areas only. Densities in individual areas may vary considerably ranging up to seven to ten residential units per acre near the center and eastern edge of the site. Commercial densities are highest in the central district and lower elsewhere. Actual densities could vary, however, depending on how individual lots and multifamily units were used.

CONCLUSIONS

This paper has outlined an approach to arranging land uses to be more responsive to the needs of public transit. The purpose is to demonstrate how planning decisions could be made to provide a greater variety of modal choices and more efficient use of transportation. Transit-sensitive land use design can be developed through the designation of transit corridor districts, which would separate transit and auto-oriented land uses. Such areas would have a mix of land uses with higher densities located near the transit route. A high-quality access system for pedestrians and bicyclists should be provided to permit easy connection between buildings and transit vehicles. Auto access should be controlled, if necessary, to prevent excessive automobile traffic within a transit corridor district. Finally, such areas should be designed to permit flexibility in land use patterns and transportation technology.

This paper has included a summary of guidelines that could be used to develop such areas and has provided an illustration of how such an area could be designed in an actual situation. Such an approach appears to be promising and may have the potential for more efficient land use and transportation patterns in the future.

ACKNOWLEDGMENTS

This project was conducted under the sponsorship of a University Research and Training grant from the Urban Mass Transportation Administration of the U.S. Department of Transportation. Additional support was provided through the University of Wisconsin, Milwaukee, and from Mark Stone.

Many organizations and people provided useful input into this report. This list includes planners, architects, and officials in Washington, D.C., Maryland, Virginia, Illinois, California, Florida, and Ontario. The authors would like to thank Norm Paulhus, Fred Ducca, Marina Drancsak, and Joe Goodman of the U.S. Department of Transportation for their helpful suggestions and comments.

REFERENCES

1. H. Rabinowitz, E. Beimborn, C. Mrotek, S. Yan, and P. Gugliotta. *The New Suburb: Analysis and Trends*. UMTA; Office of Technology Sharing, U.S. Department of Transportation, 1991.
2. R. B. Teska. High Accessibility Corridors in Metropolitan Areas. *Barton-Aschman Letter*, Sept. 1971.
3. R. B. Treska. Social, Economic, and Environmental Aspects of a System of High Accessibility Corridors. In *Highway Research Record 356*, TRB, National Research Council, Washington, D.C.

4. Duany/Plater-Zyberk. Livable Suburbs, The Neo-Traditional Model, An Alternative to Suburban Sprawl. Presented at 8th International Conference on Making Cities Livable, Siena, Italy, 1990.
5. P. Calthorpe, H. Fraker, M. Mack, D. Prowler, D. Sellers, B. Small, and D. Solomon. *The Pedestrian Pocketbook: A New Suburban Design Strategy* (D. Delbaugh, ed.). Princeton Architectural Press, University of Washington, St. Louis, Mo. 1989.
6. Snohomish County Transportation Authority. *A Guide to Land Use and Public Transportation for Snohomish County*. SNOTRAN; Office of Technology Sharing, U.S. Department of Transportation, 1989.
7. E. Kadesh. *Encouraging Public Transportation Through Effective Land Use Actions*. Municipality of Metropolitan Seattle; U.S. Department of Transportation, 1987.
8. Delcan Corporation. *Guide to Transit Considerations in the Subdivision Design and Approval Process*. Roads and Transportation Association of Canada, 1990.
9. E. Beimborn, H. Rabinowitz, P. Gugliotta, C. Mrotek, and S. Yan. *Guidelines for Transit Sensitive Land Use Design*. UMTA; Office of Technology Sharing, U.S. Department of Transportation, 1991.
10. B. S. Pushkarev and J. M. Zupan. *Public Transportation and Land Use Policy*. Indiana University Press, Bloomington, 1977.
11. N. Achs. Road Blocks to Public Transit. *American City and County Magazine*. Jan. 1991, pp. 28–31.

The opinions expressed are those of the authors and not necessarily those of the project sponsor.

Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Abridgment

What Did You Do for Lunch Today? Midday Activities of Downtown Workers

FRANK SPIELBERG AND A. T. STODDARD

Downtown transit circulators are often seen as a way to improve the connections between work locations and shopping opportunities. To evaluate the effectiveness of such services it is necessary to understand the way downtown workers use available services. The results of a survey of the midday travel of downtown workers are discussed and rates for visits to various activities are reported.

One of the benefits of working in a downtown location is the availability of shopping and service opportunities during daytime hours. Downtown workers frequently use their lunch hours to take care of shopping or other personal business activities that otherwise would have required separate trips or a stop after work. In turn, the use of shops and services by downtown workers contributes to the economic vitality of the downtown area.

To facilitate use of downtown businesses by downtown workers, many cities have established or studied transit circulator services. By extending the distance that can easily be covered, the circulators enable downtown businesses to attract customers from a wider area. Similarly, suburban activity complexes consider shuttle services to link employment sites with retail services. The goals are to stimulate shopping activity, make the workplace more desirable and, in some cases, to foster transit use or ridesharing by providing workers with an alternative to their own car for midday travel.

Design and evaluation of both downtown and suburban shuttles require an understanding of the activity patterns of the workers to be served. Unlike home-based trips for which extensive data are available from home interview surveys and the U.S. Census, the trips of interest here are non-home based. Few data are available on the nature of these trips and their generation rates.

DATA COLLECTION

As part of a study to assess the feasibility of a transit shuttle in the downtown area of Colorado Springs (population approximately 300,000), data were collected on the daytime activity patterns of daytime workers.

F. Spielberg, SG Associates, Inc., 4200 Daniels Avenue, Annandale, Va. 22003. A. T. Stoddard, Leigh, Scott & Cleary, Inc., 19 Boulder Court, Colorado Springs, Colo. 80903.

Types of Data

The data collected were of two types: (a) shops and services within the downtown area used during the prior week by workers and (b) trip lengths of pedestrian travel. The former data—activities visited—were collected by a place-of-work survey. This survey also asked where the worker ate lunch the previous day and whether the worker had made any trips out of the workplace on the previous day. The latter data—pedestrian trip lengths—were collected by an intercept survey of a sample of pedestrians on selected block faces within the downtown. Interrupted pedestrians were asked the purpose of their walking trip, how far they had walked to reach the interview location, and how much farther they expected to walk to reach their destination. The survey data were factored by trip length strata to account for the higher probability of intercepting longer trips.

Area Characteristics

The downtown area studied is, overall, about 20 blocks long by 6 blocks wide. The area includes 18,000 workers in almost 6 million ft^2 of commercial, retail, and government space. A total of 21 percent of the space is devoted to retail and restaurant uses; 26 percent is devoted to government. The majority of activity is concentrated in a core area roughly four blocks by five blocks.

FINDINGS

The results of the employee activity survey are presented in Table 1, which summarizes rates for trips reported by the 452 survey respondents to activities in downtown within walking distance of the workplace, as perceived by the respondent, to activities in the downtown area but beyond walking distance, and trips made during the 7-day period to activities outside the downtown area.

In the survey area, lunch hours are relatively long. A total of 93 percent of the workers reported having 1 hr for lunch. The activity visitation rates must be viewed with this time in mind. In areas in which 30- or 45-min lunch periods are the norm, lower activity rates could be expected.

TABLE 1 DAILY RATES FOR ACTIVITIES VISITED BY DOWNTOWN WORKERS

Activity Visited	In Downtown Walking Distance	In Downtown Beyond Walking	Total Downtown	Not in Downtown	Total
Bank	0.21	0.02	0.23	0.02	0.25
Fast Food Restaurant	0.13	0.04	0.16	0.03	0.20
Table Restaurant	0.13	0.03	0.16	0.02	0.18
Drug Store	0.10	0.01	0.11	0.03	0.14
Card Shop	0.08	0.00	0.09	0.01	0.10
Casual Food	0.06	0.01	0.07	0.01	0.08
Convenience Store	0.03	0.03	0.06	0.07	0.13
Health Club	0.05	0.01	0.06	0.02	0.08
Book Store	0.05	0.00	0.05	0.01	0.06
Women's Clothing	0.04	0.00	0.05	0.03	0.07
Library	0.03	0.00	0.04	0.01	0.05
Variety Store	0.02	0.01	0.04	0.03	0.06
Other	0.03	0.01	0.03	0.02	0.05
Medical/Dental	0.02	0.01	0.03	0.02	0.05
Child Care	0.01	0.02	0.03	0.04	0.07
Dry Cleaner	0.01	0.01	0.02	0.03	0.05
Department Store	0.01	0.01	0.02	0.05	0.07
Printer/Copy Center	0.02	0.00	0.02	0.00	0.03
Specialty Items	0.02	0.00	0.02	0.01	0.03
Shoe Repair	0.02	0.00	0.02	0.00	0.02
Travel Agent	0.01	0.00	0.01	0.01	0.02
Hardware	0.00	0.01	0.01	0.02	0.04
Camera/Photo.	0.01	0.00	0.01	0.00	0.01
Children's Clothing	0.00	0.01	0.01	0.01	0.02
Men's Clothing	0.01	0.00	0.01	0.01	0.02
Computers etc.	0.00	0.00	0.00	0.00	0.01
Electronics	0.00	0.00	0.00	0.00	0.00
Furn./Appliance	0.00	0.00	0.00	0.01	0.01
Total	1.10	0.25	1.35	0.53	1.88

Trips out of Building

In the downtown area studied, 60 percent of the workers reported leaving the building in which their workplace was located at least once during the day. Hooper (*1*) reports the incidence of midday out-of-building travel ranging from 42 percent to 50 percent for a sample of diverse office activity complexes in suburban locations. Hooper, however, did not determine the length of lunch periods, so a direct comparison of trip rates may not be valid. A survey by the authors of workers in a corridor outside New York City that includes both suburban office parks and a traditional downtown found daytime trips away from the workplace to be 39 percent for office park employees and 58 percent for downtown employees. These data are summarized below:

Survey	*Proportion of Workers Making at Least One Trip out of Building* (%)
Downtown Colorado Springs	60
Suburban N.Y.—downtown	58
—office park	39
Hooper (*1*)—suburban centers	42–58

These data suggest that when opportunities for daytime activities are available, workers will use these facilities. When the activities are in a walking environment, about 60 percent of workers will travel outside the building, compared with only about 40 percent when walking is not an easy option.

The reported data on activities within the downtown visited away from the office showed 3,055 trips over a 5-day working period by the workers in the sample, yielding a rate of 1.35 activities visited per day per worker. Of these, 1.10 visits were to places within walking distance of the workplace, as defined by the respondent.

The most frequently visited activity type is food related—0.316 visits per employee per day for the combination of fast food restaurants, table service restaurants, and casual food (e.g., ice cream). On average, each downtown worker buys a meal or other food every third day.

Lunch Patterns

Lunchtime patterns are slightly different from overall midday travel patterns. In the downtown area under study, 29 percent of the workers left their buildings for lunch. In the New York area studies, the rates were 30 percent in the downtown sites and 26 percent in the office park sites. Hooper (*1*), in contrast, reports rates for lunch outside the building of 31 percent to 52 percent, with a mean of 40 percent (Table 2).

The suburban Baltimore site included some single buildings with very large employment. The office facilities were more "scattered-site" than multibuilding complexes. These data suggest that, where nearby lunch opportunities are available outside the building, about one-quarter to one-third of workers will leave the building of their workplace for lunch.

Other Activities

As seen in Figure 1 and Table 1, the most frequently visited non-food activity in downtown is banking, with 0.21 visits per employee per day. Expressed another way, each downtown worker visits a bank just over once each week.

The rates for other retail and service activities are shown in the tables and figures. Of interest are card shops in the downtown, visited at least once in the previous week by over 40 percent of the surveyed workers. Table 1 also documents the use of downtown versus non-downtown retail outlets by downtown workers. Drugstores, health clubs, and bookstores all have much higher rates for downtown. Many retail (women's clothes, men's clothes) stores have similar rates downtown and outside downtown.

Also of interest is the relationship between visits by downtown workers to downtown activities compared with their reported rates of visits to non-downtown activities. Total visits to all types of activities, both within and outside the downtown, were reported to average 1.88 per worker per day. Of these, 1.35 or 72 percent were to downtown sites. Employees working in downtown accomplished a majority of their errands during their time downtown. Those activities with higher rates for visits outside downtown were to such locations as hardware stores, appliance dealers, department stores, and convenience stores. Each of these activities has a strong au-

TABLE 2 LUNCHTIME ACTIVITY OF WORKERS

	Did Not Eat Lunch	Ate Lunch In Building	Ate Lunch Outside Building
Downtown of Colorado Springs	5%	66%	29%
Suburban NY -- Downtown	6%	64%	30%
-- Office Park	8%	66%	26%
Hooper (1) -- Suburban Centers	7%	53%	40%
Suburban Baltimore (2)	5%	79%	16%

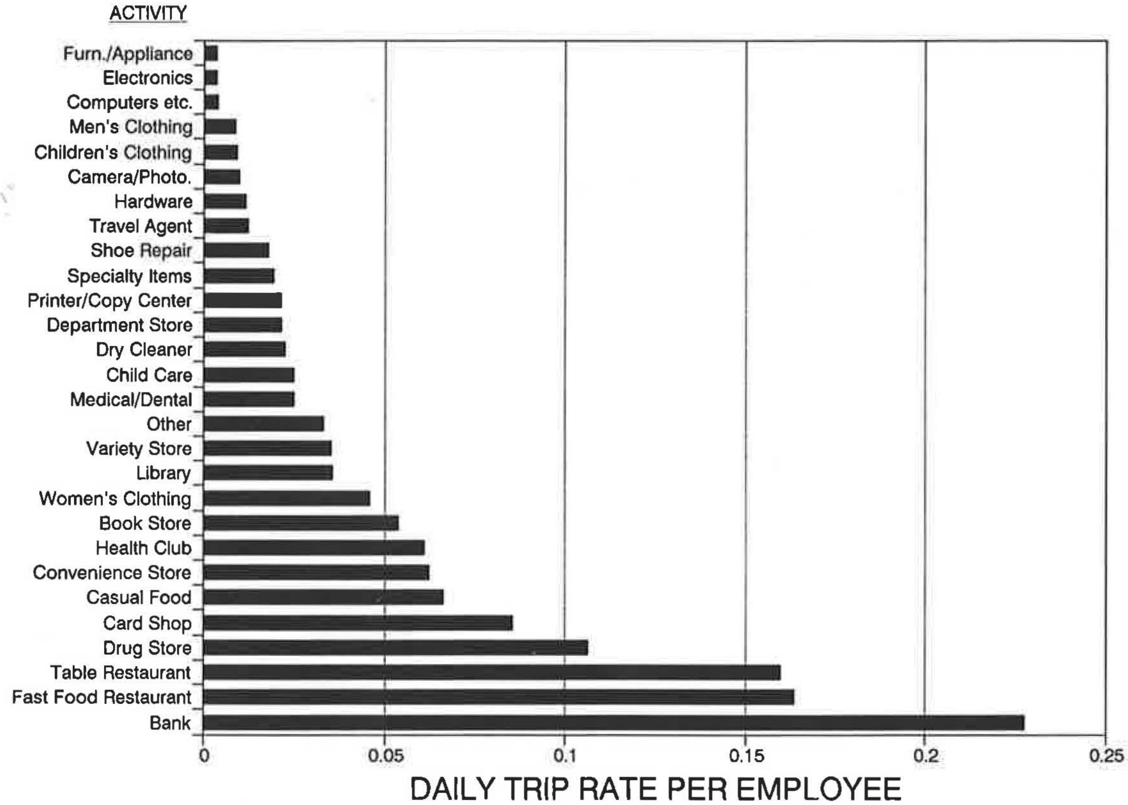


FIGURE 1 Employee trip rates: trips to downtown activities.

tomobile orientation, primarily because of the nature of the retail products.

TRIP LENGTHS

The length of walking trips in the downtown area was quite short. Over 50 percent were two blocks or less. By purpose, the 50th percentile walk trip lengths were as follows:

Purpose	*Length (blocks)*
Work related	2.8
Shop	2.2
Personal business	1.0
Eat meal	1.0

Only 10 percent of the walk trips were more than six blocks long. Most people can walk six blocks in about 12 to 15 min, illustrating the importance of frequent service if a downtown shuttle service is to be attractive to a significant portion of the target market.

CONCLUSION

Workers in downtown areas do make substantial use of the shopping and service opportunities that are available. Although the bulk of activity is for routine day-to-day needs (e.g., food and banking), workers also use many other types of shops if they are available and easily accessible. The bulk of midday trips are short—two to three blocks—taking 5 to 8 min of walking time. To achieve the synergistic effects of having working and shopping locations in a common area, they must be in close proximity and linked by a frequent, convenient transit service. Although this finding is based on a study of downtown workers, a comparison with other studies indicates that it is likely that similar patterns may hold for workers in suburban activity complexes. The differences between rates for downtown and suburban centers may be strongly influenced by the available opportunities and the length of time available for lunch. These findings suggest (a) that the economic vitality of downtown areas is strengthened by having a mix of both office and retail uses and (b) that noontime traffic in suburban complexes can be reduced by providing retail opportunities within walking distance of workplaces.

ACKNOWLEDGMENT

The studies supporting the materials presented in this paper were funded, in part, by grants from UMTA, now the Federal Transit Administration (FTA).

REFERENCES

1. K. G. Hooper. *NCHRP Report 323: Travel Characteristics at Large-Scale Suburban Activity Centers.* TRB, National Research Council, Washington, D.C., 1989.
2. SG Associates, Inc. *Strategic Plan for the Transportation Needs of the Greater Baltimore-Washington International Airport Employment Area.* Greater BWI Commuter Transportation Center, Inc., Hanover, Md., 1989.

Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Abridgment

Access to Jobs: A Public Transit Agency's Initiative for Privately Operated Service

ROBERT J. KLEIN

An ongoing Federal Transit Administration (FTA) Entrepreneurial Services Challenge Grant program called "Access to Jobs" is described. FTA presented the Maryland Mass Transit Administration with the 1991 Administrator's Award for Excellence in Service Enhancement in recognition of this local effort to encourage privately operated van and minibus service. This program builds on the principles of a free market: rules and oversight are kept to a minimum, transportation providers and employers are expected to work in their own self-interest, and providers are given financial assistance based on results. Access to Jobs can serve as a regional model for fostering privately operated local service.

At a recent TRB committee meeting on bus transit systems, a committee member proclaimed that the push for private transit is simply an effort to dismantle public transit. The Maryland Mass Transit Administration (MTA) aims to challenge this opinion with a program called "Access to Jobs."

In 1988, MTA was asked by a progressive local transportation provider (Yellow Transportation, Inc.) and the Baltimore Regional Council of Governments to act as the grant sponsor for a Federal Transit Administration (FTA) Entrepreneurial Services Challenge Grant. Although impressed by the proposal, MTA responded that signing off on it would give an unfair advantage to a single provider. As a result, MTA tailored a Baltimore regional program based on the principles of the federal program. In recognition of the Access to Jobs program, FTA awarded MTA its 1991 Administrator's Award for Excellence in Service Enhancement.

In 1990, FTA accorded MTA a $550,000 3-year grant to prove the feasibility of a regionally managed program. Beyond the FTA funding with its $150,000 state match, providers will contribute $125,000 in capital funding. The start has been promising. Yellow Transportation started the first Access to Jobs service, a single van operating between two suburban counties. The sponsoring employer was the financial investment company T. Rowe Price, Inc. Although this service stopped operating after 3 months, MTA gained valuable experience and continues to promote the program to employers. This paper describes the program, identifies its benefits, and points out the lessons learned.

PURPOSE

The combination of the shift of jobs to suburban areas and the high cost of providing transit for these locations resulted in the creation of this program to foster private transit. The phrase MTA uses to describe this program is, "A customized transit service provided by private operators for suburban employers."

The intent of the program is to create self-sufficient services. Thus, the key determination in awarding grants is the promise of financial success. This emphasis on financial success places far greater importance on marketplace considerations than does traditional public sector service planning.

STRUCTURE

The basic structure of the program encourages providers to submit to MTA proposals to operate commuter van and minibus service in places or at times of the day without existing transit service. Service characteristics are generally decided jointly by sponsoring employers and providers. For accepted proposals, providers will receive monthly payments from MTA equal to roughly a quarter of total service costs.

The program uses a grant-in-aid approach for distributing financial aid. This process permits providers to request funding assistance in much the same way universities obtain research funds. MTA funds proposals judged to have sufficient merit on a first-come, first-served basis. The very essence of the program requires that the initiative remain with providers and sponsoring employers. The competitive procurement process and its tight uniform structure would, in contrast, require detailed planning and considerably more government money.

MTA promotes the program in two ways. One is the enlistment of private operators that are ready, willing, and able to deliver transit services. To date, 11 providers have registered for the program. These providers are included in a "provider list," which spells out key points of interest to employers considering the program. MTA does not restrict any provider from registering. Instead, the provider list gives objective information that enables employers to make their own assessment of registered providers.

The second way MTA promotes the program is through an outreach effort directed at suburban employers. MTA estimates that a typical 35-min one-way trip with a privately operated van service could cost an employee $6.00/day. Such fares become a major hardship for low-wage workers. However, because certain employers stand to gain greatly by reaching new labor markets, they are the most logical group to buy down transit fares of their own workers. MTA aims to get the message to employers that, compared with parking costs,

Maryland Mass Transit Administration, 300 West Lexington Street, Baltimore, Md. 21201-3415.

the Access to Jobs program can solve their labor shortage problems for a reasonable cost.

To date, MTA has sent program brochures to 800 employers, held group meetings sponsored by private industrial councils and chambers of commerce, promoted the program in the media and in business newsletters, and individually met with over 25 employers.

ADVISORY COMMITTEE

Although MTA is directly responsible for program administration, the innovative structure of the program created a need for an advisory committee to oversee the program and to make recommendations on provider grant applications. Its members consist of representatives from the six jurisdictions of the Baltimore region, the Baltimore Regional Council of Governments, the state Department of Economic and Employment Development, the state Department of Transportation of which MTA is a part, and the Greater Baltimore Committee (a chamber of commerce). In addition, the Maryland Public Service Commission and two transportation management associations participate.

FTA REQUIREMENTS

Because FTA funds the Access to Jobs program, certain federal requirements exist. FTA has been flexible when the requirements became impediments to the program. For example, FTA allowed the grant period to be extended to 2 years when providers and the advisory committee strongly objected to a 1-year period.

The following is a list of FTA requirements related to the Access to Jobs program:

1. Must be open-door service (public can ride);
2. Must be new service (conditional exceptions are possible);
3. Must not compete with preexisting private service;
4. Must not receive other government subsidies;
5. Must be wheelchair-accessible service;
6. MTA must not take title to program vehicles;
7. Capital grants must not exceed 75 percent of vehicle cost;
8. Minimum 25 percent in-kind capital contribution is required;
9. Grants must not exceed 2 years;
10. Providers contributing additional in-kind capital must receive special consideration;
11. Small and minority businesses must receive special consideration;
12. Proposals that can be carried out quickly must receive special consideration; and
13. Providers must submit Section 15 ridership and mileage data.

The requirements helped to define the program. The special considerations have not become an issue because MTA has yet to be in the situation of making selections between proposals.

APPLICATION PROCESS

Only providers are eligible to submit the two-part application for grants. The first part, a proposer's questionnaire, establishes the provider's interest in the program and consists of information useful to employers in deciding which provider to contract (e.g., insurance coverage, experience, vehicles in fleet, and safety record).

The application requires typical transit service information—routing, schedules, trips, vehicles required, stops, fares, etc. In addition, a provider must project financial data on service cost and revenue for 3 years. These data allow both MTA and the advisory committee to assess the prospects for financial success of the proposed service.

REVIEW OF PROPOSALS

MTA, with the assistance of the advisory committee, reviews and approves grant applications based on three sets of criteria.

The first set is constraints. MTA added several requirements to the FTA requirements. Service must be principally work trip related. This requirement focuses the program on jobs. Providers must obtain Public Service Commission authority to operate, which means that providers meet minimum safety and insurance standards. MTA also stipulates that proposed service cannot compete with existing MTA service and that vehicles operated should be smaller than full-sized transit buses. If service justifies full-sized buses, MTA believes that such service should be integrated into the MTA system.

The second set of criteria is the core of the evaluation process. After meeting the constraints, the proposal is assessed by MTA and the advisory committee for reasonableness and the core evaluation factors. These include whether the fares, ridership projections, revenue projections, schedules, and cost estimates are reasonable.

The third set of criteria consists of special considerations used in considering awards once the first two are judged acceptable. To the FTA list of special considerations, MTA added two factors—3 years or more of experience and coordination with existing public transportation.

To date, MTA has formally reviewed three service proposals. The advisory committee and MTA have approved two of the three routes requested.

BENEFITS TO EMPLOYERS

Employers are key to the success of the Access to Jobs program. If they do not foresee sufficient benefit from sponsoring transit service, the program cannot succeed. Employers stand to gain in several ways from this program.

It is common for low-wage workers to be without automobiles. This lack of personal transportation combines with the shift to low-density suburban employment sites to signal the need for new transit options. If employers experience trouble in recruiting needed workers, they will act. As one midsized employer frankly put it, "When the lack of public transportation clearly hurts our profitability, we will pay for this kind of service."

Many low-income suburban workers carpool in unreliable old cars. Others walk long distances from existing bus routes in areas that often are without sidewalks and lighting. Access to Jobs can bring new convenience to such workers, which translates into more reliability through reduced absenteeism, less turnover, and reduced retraining.

Starting an Access to Jobs service can involve other financial advantages for employers. Because the employers select and negotiate with the providers, the program should lead to less expensive services. Employers also may benefit from federal subsidies and tax credits for hiring residents of poverty areas and by avoiding the construction of new parking facilities.

BENEFITS TO PROVIDERS

The main financial benefit of the program is the 75 percent capital assistance. This assistance, which comes directly from FTA's support, is distributed based on per-vehicle mileage rates. MTA established two depreciation rates. The rate for automobiles and minivans is \$0.20/mi and, for larger vehicles, \$0.30/mi. These rates take into consideration vehicle costs, including spare vehicles, and sales tax. Costs were divided by average vehicle mileage expectancy. The 25 percent provider match was included to arrive at the per-mile capital reimbursement rates. MTA pays these rates monthly for both revenue and deadhead mileage.

Besides the FTA capital assistance, the program distributes up to \$10,000 in state money for marketing per provider. MTA sees this money as helping to offset the cost of promoting service and carrying on management activities. MTA distributes this money in the same way it distributes the capital assistance portion.

Although MTA informs providers that they are responsible for finding their own business, the program brings employers and providers together through the employer outreach effort. In addition, the program offers other assistance to providers, including help with ridership analysis, service planning, and marketing.

BENEFITS TO TRANSIT AGENCY

MTA sees three basic reasons why a transit agency should consider starting a program similar to Access to Jobs. First, it helps fulfill its mission of increasing public mobility. Second, it provides an inexpensive way to expand service. Third, it provides political benefits.

All transit agencies face some financial constraints. Therefore, when public transit agencies promote inexpensive private transit, public transit dollars will go further. MTA estimates that privately operated van and minibus service costs less than half of what it would cost to operate service itself.

Any government agency needs to be aware of political considerations. The single largest funding source for MTA is the state. Jobs, as well as political power, have shifted to the suburbs. Common sense requires that suburban legislators need to see services for their constituents. Additionally, it is increasingly important that persons receiving public assistance have access to employment opportunities.

LESSONS LEARNED

The following lessons already have been learned:

1. Employers are key to the expansion of transit to suburban job sites. The low-density nature of suburban employment means that public transit agencies cannot afford to provide traditional service to these areas. As reverse commuting increases, more suburban employers will financially support transit service. However, with little transit experience, most employers are initially shocked by the cost of service. Also, the current recession has reduced the need and the resources to initiate transit activities.
2. Keep the program procedures as simple as possible. To make the accounting process manageable, MTA developed uniform per-mile reimbursement rates. The more a reimbursement formula reflects a provider's actual expenses, the more complex the program becomes. Such complexity can confuse providers and cause accounting problems.
3. Building accountability into the program discourages less-qualified providers. Some providers and many persons interested in becoming providers expect financial assistance before any service is operating. Most of these providers do not register for the program.
4. The advisory committee is extremely useful in the start-up phase and in reviewing applications. However, as policy issues are resolved, its involvement decreases and interest declines. Coordination with the regulatory agency responsible for overseeing private for-hire transportation is essential because overlapping regulatory authority could inhibit program success.
5. Flexibility in program structure is essential. The grant-in-aid structure guarantees that providers will keep the business they develop rather than lose it to other providers through a competitive procurement process.

CONCLUSION

MTA is confident that the Access to Jobs program rests on the sound principle of helping providers and employers do what is in their own best interests, while maintaining a high level of accountability. Although the current economic recession has essentially left it untested, the program is in place to respond immediately. In the meantime, MTA continues marketing the program and is pursuing ways to increase the financial assistance for providers.

Jimmy Yu of FTA's Office of Private Sector Initiatives advised MTA that this program will raise questions that neither FTA nor MTA will initially know how to answer. According to Yu, "Approaches and various aspects of the program will surely need refinement as the program gains experience."

Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Abridgment

Public Transportation's Future in the New York Metropolitan Area

Athanassios K. Bladikas, Ahmad Sadegh, and Louis J. Pignataro

Public transportation plays a significant role in the New York metropolitan region's mobility, and its relative importance as a mode of passenger transportation is unprecedented in comparison with the rest of the nation. In the year 2015 the region will be, as it is today, a multinucleic megalopolis with the Manhattan central business district (CBD) continuing to be the primary focus of economic activity, whereas the suburbs will maintain their healthy growth. The additional travel demand that will have to be satisfied by 2015 is approximately 1.8 million trips per day, which is larger than the total current ridership of some of the nation's largest transit systems. To meet the region's future mobility needs, substantial additions to existing capacity will be required, particularly since the new demand will materialize in corridors that are already operating at capacity. Three basic alternative scenarios for the future are presented. They differ in terms of the amount of investment they require and are labeled minimum, moderate, and significant. The required improvements, the costs associated with them, the possible financing strategies needed, and the impacts on the region under each scenario are presented. The approximately $3 billion that has to be spent annually on the region's public transportation systems is a challenge that can be met if all levels of government continue their funding at current levels, the farebox recovery ratio remains constant, costs are contained, and new dedicated sources of funding are tapped.

Public transportation plays a crucial role in the New York metropolitan region's mobility. Although only 7.9 percent of the nation's population resided in this region in 1980, its public transportation system carried 26.7 percent of the nation's passengers, provided 30.7 percent of the vehicle-miles of service, expended 40 percent of the public transportation's budget and collected 60 percent of all operating revenues excluding subsidies (*1*,*2*). This extreme concentration and utilization of the nation's public transportation resources in the New York metropolitan region is a result of its demographics, land uses, and economic geography.

SUMMARY OF TRAVEL DEMAND IN 2015

In 2015 the region will be, as it is today, a multinucleic megalopolis with the Manhattan central business district (CBD) continuing to be the primary focus of economic activity, and the suburbs will maintain their healthy growth (*3*). As a result of the increases in population and economic activity, it was estimated that demand for travel to the Manhattan CBD will increase by about 286,000 daily trips. The city of New York will generate 81 percent of these trips. New Jersey's contribution will be about 12 percent, and the remainder will come from the eastern and northern suburbs.

Although the additional trips to the CBD are substantial, the additional demand for travel among the region's suburbs will be over 1.4 million daily trips. About 750,000 of these trips will be added in northern New Jersey, about 400,000 in the New York counties north of the city of New York, and about 250,000 on Long Island.

If all new trips are added together, the total new travel demand that has to be satisfied will be approximately 1.8 million trips per day—a staggering number that is close to or exceeds the total ridership of some of the nation's largest transit systems.

ALTERNATIVE INVESTMENT STRATEGIES

To meet the region's future mobility needs, substantial additions to existing capacity will be required, particularly since the new demand will materialize in corridors that are already operating at capacity (*3*). In addition, public transportation's modal share should increase in the future to alleviate congestion and reduce environmental pollution. Three basic alternative future scenarios are presented. They differ in terms of the amount of investment they require and they are labeled minimum, moderate, and significant.

Because of the region's size, diversity, and the complex and multimodal existing transportation system, any solution that attempts to solve the region's future mobility needs will have to be multimodal.

IMPROVEMENTS REQUIRED

The required improvements to meet future mobility needs that are mentioned here are not detailed. This lack of detail arises in part from the very long time horizon of this study; the study's scope, which was to assess the region's basic transportation needs; and the study's nature and political significance, which can make local agencies and interest groups feel uncomfortable by including specific projects.

Minimum Investment

With minimal investment, no additional capacity is going to be added, but all systems will have to be kept in a state of

Center for Transportation Studies and Research, New Jersey Institute of Technology, Newark, N.J. 07102.

good repair (i.e., no system components will have exceeded their useful life and all backlog needs will have been eliminated) (*4*). Currently, the region's public transportation systems are not in a state of good repair, but they are rapidly getting there. Naturally, the operating effort will also have to be maintained at current levels. Namely, existing routes and schedules and the equipment and personnel needed to support them will have to continue to be provided. This investment alternative is effectively a no-growth scenario. The only benefit achieved from investing at this level is that at least the region's infrastructure will not deteriorate.

Moderate Investment

With moderate investment, system capacity additions are considered that are capable of accommodating future demand at the current level of service. This investment alternative should be the minimum acceptable. The critical corridors/areas in the year 2015 will be

- The Queens- and Brooklyn-to-Manhattan corridors;
- The New Jersey-to-Manhattan corridors; and
- Suburb-to-suburb travel in northern New Jersey, northern New York, and Long Island.

By the year 2015, approximately 160,000 new daily trips will have to be made to Manhattan from Brooklyn and Queens. The majority of these trips will have to be made by public transportation. To serve this demand, the Queens Boulevard Connection is the minimum capital improvement required. This linkage will connect the New York City Transit Authority's E and F subway lines in Queens with the 63rd Street tunnel under the East River. The tunnel's construction is completed and was scheduled to open by the end of 1989. The Queens Boulevard Connection can be completed by the late 1990s.

To serve the additional 35,000 trips in the New Jersey-to-Manhattan corridor, a new Hudson crossing will be required. None of the existing systems (commuter rail, buses, PATH, and ferries) are capable of meeting this new demand.

The 1.4 million new suburb-to-suburb trips pose a special problem. It is not only their magnitude, but also their geographical dispersion, that makes their service infeasible through conventional public transportation. Naturally, not all of these trips will have to be satisfied by public transportation. If public transportation maintains its modal share, satisfying demand in the Connecticut sector will not be critical, but substantial new services will have to be provided in the remaining sectors. All improvements planned in the New Jersey sector (e.g., Kearny Connection, Secaucus Transfer, etc.) will have to be implemented.

Significant Investment

If the region is to grow, investments in the public transportation system should take place at the significant investment level of this scenario. New services will have to be provided that will not only serve the future demand but will also improve the existing level of service from the E to F range to about the middle of level of service D in the peak period. That goal may be impossible to achieve in parts of the system, because it would imply the doubling of current New York City Transit Authority (NYCTA) subway service along portions of the system. However, the addition of capacity to at least corridors that are already seriously congested and will have to be burdened with most of the new demand, will make significant contributions toward service improvements.

For this scenario, the completion of the entire length (from the lower tip of Manhattan to the Bronx) of the Second Avenue subway line is a must, as well as two additional tunnels under the East River. Both of these tunnels will connect Brooklyn with Manhattan, one of them at the lower end to relieve congestion on the Manhattan bridge and in existing tunnels, and the other farther north (approximately where the Williamsburg bridge is) to relieve congestion on that bridge and in existing tunnels. The Long Island railroad should become fully electrified, connected with the second level of the 63rd Street tunnel, and a new terminal should be constructed on the East Side of Manhattan to relieve Grand Central and Penn stations. An additional transit-dedicated Trans-Hudson facility will also be needed to carry rail or bus traffic from New Jersey into Manhattan.

The remaining commuter railroads (except for the Connecticut-to-Manhattan corridor) should at least triple the service they provide currently and extend further into the suburbs. Additional terminal and exclusive movement facilities for buses will also be required.

Multimodal Alternatives

The region's infrastructure still has an enormous potential to move additional people if public transportation services are used. The four East River bridges collectively now serve about 1 million daily trips; this is half the trip service they used to provide in their peak year (50 to 85 years ago) when they were used more intensively by public transportation services.

Although public transportation can unquestionably better serve large masses of travelers than can the road system, it is impossible to provide an all-transit solution for all future needs. The region's size, however, allows the assumption that the public transportation system can expand continuously and in direct proportion to its modal share of all trips made in the region. For every 1 percent increase in public transportation's modal share over the current 28 percent of all regional trips, 3.5 percent more service will have to be provided, and expenditures for this mode will have to be increased by the same amount.

COST OF IMPROVEMENTS

The cost of providing public transportation services in the future could be called staggering, if any other than the nation's most public transportation intensive region were concerned. But, the price to be paid to ensure mobility is relatively modest, if one considers the benefits that this mobility is going to produce.

Minimum Investment

The region's transit systems currently operate with a farebox recovery ratio of 55 percent. As of 1987, operating subsidies are about $2 billion a year, and an additional $2 billion is spent annually on capital needs. Under this minimum investment alternative, since no additional services will be initiated, the annual cost will remain the same (in current dollars) and the total needs up to the year 2015 will be $100 billion. Two basic assumptions are implicit in this estimate: that public transportation operating and capital costs will keep pace with inflation and that the farebox recovery ratio will remain at 55 percent. There is no compelling reason that can violate these two assumptions.

Moderate Investment

Under the moderate investment scenario, additional costs will be needed for new capital initiatives, and operating costs will increase. It is assumed that operating costs will increase in direct proportion to increases in ridership. Under these assumptions, an additional $100 million annually and $250 million in capital costs will be required for operating expense subsidies, bringing the annual operating subsidy and capital needs to $2.1 billion and $2.25 billion, respectively. These figures bring the total operating subsidy and capital requirements for the period up to the year 2015 to $52.5 billion and $56.25 billion respectively, for a total of $108.75 billion.

Significant Investment

The significant investment scenario is not only capital intensive, but it also provides for an expansion and intensification of operations. Operating subsidy and capital requirements will each be $500 million over the current levels of $2.5 billion each annually. For the entire period up to 2015 the total needs will be $125 billion.

Multimodal Alternatives

All previous estimates were made under the assumption that public transportation will maintain its existing share in all sectors. However, if public transportation's modal share increases, additional expenditures will be required in the amounts of $3.5 billion, $3.8 billion, and $4.4 billion for the minimum, moderate, and significant alternatives, respectively, for every 1 percent increase in the mode's share.

FINANCING STRATEGIES

No new public transportation funding source is expected to materialize in the future. Operating and capital needs that are not met by farebox revenues will have to be funded through other sources. Although no new source is expected to become available in the future, the relative share that each of the existing sources contributes does not have to remain the same as it is now.

Minimum Investment

Since no additional expenditures over the current levels are expected under the minimum investment scenario, if the current funding sources maintain their support at current levels, no problems should arise. An implicit assumption made here is that funds from all current sources will be increasing at the rate of inflation.

Moderate Investment

The additional needs of the moderate investment scenario are indeed moderate in overall magnitude according to regional standards. The additional $350 million per year for both capital and operating expenses can be raised in a variety of ways. The federal government should absorb at least half of the $250 million in capital requirements, leaving a total of $225 million to be raised locally. This figure is only five-hundredths of one percent of the region's average aggregate income over the next 25 years and could be raised if each worker paid about $22 annually, if every vehicle paid about 0.5 cents per mi, or if every public transportation user paid a fare that is 3 cents higher than the current fare.

Although it is possible to raise the additional funds locally, the need exists to develop a local determination to establish dedicated funding sources. The region's agencies, political leadership, interest groups, and the general public should work cooperatively toward the development of an agenda that will accomplish relatively soon this source of funding.

Significant Investment

If the same assumption that was made for the previous scenario were made for the significant investment scenario, a total of $750 million would have to be raised locally. Dedicating a source that can raise this amount will be problematic. For example, a regional gasoline tax of about 32 cents per gallon will be required, an amount that under normal circumstances is practically impossible to be accepted. However, the improvements do not have to be implemented immediately. If gasoline taxes were to be raised gradually at about 1 to 2 cents per gallon per year, the funds could be raised and opposition to the funding mechanism could be minimized. Although a gasoline tax was mentioned as an example, the same is true for any other dedicated funding mechanism.

CONCLUSIONS

Substantial expenditures will be required for the region's public transportation systems. Approximately $3 billion per year or a total of $125 billion has to be spent up to the year 2015 if the region is to grow as anticipated. Although it is definitely a challenge, this goal can be met. Transportation professionals, in whose hands planning for the region's future is entrusted, are aware of the problem's magnitude as well as public transportation's contribution to the region's economic vitality. It is hoped that public understanding and political will can supply the resources needed to provide solutions.

ACKNOWLEDGMENTS

Funding for this study was provided by the U.S. Department of Transportation, Office of the Secretary, and the contract was administered by New Jersey Department of Transportation. The authors are particularly indebted to their colleagues, Robert Burchell, W. Patrick Beaton, and Lap Q. Nguyen, of the Center for Urban Policy Research at Rutgers University. The authors are also indebted to the members of the project's Steering Committee.

REFERENCES

1. *Regional Transportation Status 1987.* PT 1240801. New York Metropolitan Transportation Council, July 1988.
2. Bureau of the Census. *Statistical Abstract of the United States,* 107th ed. U.S. Government Printing Office, 1987.
3. L. Q. Nguyen, W. P. Beaton, L. J. Pignataro, A. K. Bladikas, A. Sadegh, and R. W. Burchell. *National Strategic Transportation Planning Case Study of the New York Metropolitan Region.* Vol. I–III. National Strategic Transportation Planning Study Steering Committee; U.S. Department of Transportation.
4. *Twenty-year Capital Needs Assessment 1987–2006.* Metropolitan Transportation Authority, 1986.

Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Cable-Propelled People Movers in Urban Environments

EDWARD S. NEUMANN

Cable-propelled people mover systems have been studied and implemented in a variety of urban applications, including airports, downtowns, feeders to regional transit, feeders to remote parking, internal circulation in large developments, and leisure facilities. A family of technologies exists that offers a wide range of performance and design characteristics. The features and application potential of the various technologies, as well as experience to date, are discussed, and a classification system that groups technologies by service type (reversible, continuous, and pulsed), capacity of transport unit, and method of support is presented. Alignment features, velocity, gradability, capacity, and costs are compared. Specific urban sites are referenced.

Previous research indicates that installation of automated people movers (APMs) in development projects has represented about 7 percent of the total project costs, which is close to but lower than typical elevator costs for developments (*1*). Ideally, the costs should be sufficiently low that little or no federal assistance would be necessary for implementation. Cable-powered APMs have been identified as an "appropriate technology" because they have potential for requiring less expensive vehicles, less sophisticated command and control systems, and less expensive guideways. Those types of systems in widespread use in ski resorts also use off-the-shelf hardware and incur lower engineering and administrative costs. Performance of cable systems can equal or be superior to more sophisticated technologies over short travel distances on relatively simple networks (two or three station shuttles). For example, continuous cable systems can offer vehicle headways as low as 8 or 9 sec.

One of the major advantages of cable technology is its ability to climb gradients with slopes as high as 100 percent or greater. Non-cable-propelled people mover technologies are limited to much lower maximum gradients of between 10 percent and 15 percent, which has a potentially significant advantage, for many urban centers within North America that have slopes exceeding 15 percent. However, general awareness of cable technology among transportation planners and engineers, architects, and land developers is limited. Research was conducted to identify and characterize available cable technologies and their application potential for urban environments.

CABLE TECHNOLOGY

The vehicle in a cable system is attached to a cable that runs in a loop between pairs of stations. Motion is imparted to the vehicle by means of the cable, the velocity of which determines the velocity of the vehicle. This moving cable commonly is referred to as a haul rope. The drive motor or motors for the cable are located at one of the terminals and usually are DC motors. The cable that moves the vehicle is wrapped around one or more large wheels called drive bullwheels, which are linked to the drive motor either directly by a shaft or via a speed-reducing gearbox.

Tension is maintained in the cable either by weights or by hydraulic or pneumatic tensioning devices that act on one of the bullwheels. The tension placed on the bullwheel creates friction along the points of contact between the cable and surface of the groove in the bullwheel, which permits the force developed at the rim of the bullwheel to be transferred to the cable and used to move the vehicles.

When the rope needs to be decelerated under normal operation, it is necessary to slow down the drive motor by reducing the amount of current passing through it. Regenerative braking also may be used. Physical braking devices are used for other than normal stops—namely service and emergency stops. The devices frequently consist of disk-type brakes located on one of the bullwheels that are powered by the drive motor. Emergency brakes also may be located on the vehicles. Along the guideway and in the stations, the position of the cable is maintained by sheaves or pulleys over and under which the cable runs. The cable is made from wire strand, is available in a number of diameters and wire configurations, and usually has a core made of a synthetic material such as polypropylene. The cable also may serve as an antenna to transmit voice and signal communications between the vehicle and central control room or terminal.

Some systems with suspended vehicles may use a second type of cable as a track to provide only support for a vehicle. Called a track rope, the cable is stationary and relatively stiff compared with the haul rope. The track is made of elements having a complex geometric cross section that lock together and develop the stiffness in the cable. It is capable of supporting heavy weight and provides a running surface or track for small wheels attached to the hanger of the vehicle. The vehicle hangs beneath the track rope. Track rope also is manufactured in a variety of designs, diameters, and strengths.

On all systems, vehicles are passive and receive no electrical power for propulsion along the guideway. With some technologies, a power rail may be provided for door operation, air conditioning, heating, lighting, and, for one technology, air levitation of the vehicle (this adds to the cost, complexity, and weight of the guideway, however). If vehicles receive no power, doors are opened in stations either by means of mechanical linkages that engage the vehicle when it approaches

Transportation Research Center, Howard R. Hughes College of Engineering, University of Nevada, Las Vegas, Nev. 89154.

the boarding area, or by means of on-board electric motors that receive power only when the vehicle is in its final stopped position and plugged into a power outlet in the terminal.

State-of-the-art cable systems feature fully automated vehicle-door opening and closing; vehicle start-up and acceleration; vehicle positioning and velocity control; vehicle spacing and headway control; vehicle deceleration and braking; and system fault or error detection, diagnosis, and response. On continuous systems, vehicles are launched automatically. Interval is controlled electronically. Doors are designed to open and close automatically.

Computers and software are used to provide command, control, and fault detection/response functions. Systems vary from vendor to vendor, but all check vehicle velocity and position, cable position, cable tension, status of motor, and all feature interlocks to prevent vehicle movement when unsafe conditions exist (e.g., open doors). All feature automatic application of service and emergency braking when system parameters warrant it. Some systems generate logs of system operation and downtown events. Technologies that have been developed in Europe have been subjected to European codes that emphasize safety.

CLASSIFICATION OF SYSTEMS

The origins of cable technology date back to the late 19th and early 20th centuries. Technologies for funiculars, gondolas, and reversible tramways evolved in the Alpine regions of Europe to meet the transportation needs of mountain areas. Today, these technologies find widespread application in ski resorts. The family of cable technologies can be classified by type of service and vehicle support technology, as shown in Table 1. The primary categories of service are reversible, continuous, and pulsed. Secondary categories of service are based on transport unit (TU) capacity.

Reversible systems feature transport units composed of single or multiple vehicles that shuttle back and forth between terminals at the ends of the line (Figure 1). Individual vehicles remain permanently attached to the cable and reverse direction at the terminals. Only one TU can run in each direction. System line capacity is dependent on system length, capacity of the TU, operating velocity, and station dwell time. Frequency of departure and wait time are dependent on system length, operating velocity, and station dwell time. Cruise velocities of present reversible systems range from 23 to nearly 40 ft/sec.

Continuous systems feature transport units that detach from the cable in stations for passenger loading (Figure 2). Single-vehicle TUs are launched from the stations automatically at preset intervals on a continuous basis. The haul rope moves continuously at a constant velocity. When launched from a station, a vehicle is accelerated to the velocity of the cable and attached to it via grips. On entry to a station, the procedure is reversed. Vehicles are unclamped from the haul rope and decelerated. Acceleration and deceleration are accomplished by frictional forces developed from a series of tires or belts that engage the clamping device or undercarriage of the vehicle. At terminals, TUs are turned around so that they always run in the same direction, rather than also running in reverse. System line capacity is dependent on the capacity of the transport unit and the headway or interval between units. Headways as low as 8 sec can be achieved for four- and six-passenger vehicles, and cruise velocities of 16 to 20 ft/sec

TABLE 1 CLASSIFICATION OF CABLE SYSTEM TECHNOLOGY

Type of Service and Vehicle Support	Small TU (4-14 pass)	Medium TU (15-49 pass)	Large TU (50-169 pass)	Very Large TU (≥ 170 pass)
Reversible-Bottom Supported				
Levitated		Otis Shuttle	Otis Shuttle	
Pneumatic Tire			VSL Metro Shuttle 6000	
Steel Wheel		*Funicular	Funicular	Funicular
Reversible-Suspended				
Cable Guideway		*Tramway	Tramway	
Rigid Guideway			Waagner-Biro Monorail	VSL Metro Shuttle 6000
Continuous-Bottom Supported				
Pneumatic Tire		Poma 2000	(Poma 2000)	
Steel Wheel	Soule SK	(Soule SK)		
Continuous-Suspended				
Cable Guideway	Detachable Gondola	Detachable Gondola		
Pulsed-Suspended				
Cable Guideway		Non-detachable Gondola	Non-detachable Gondola	

* TU capacity is smaller than typical for this type of technology; few examples exist
( ) Technology under development

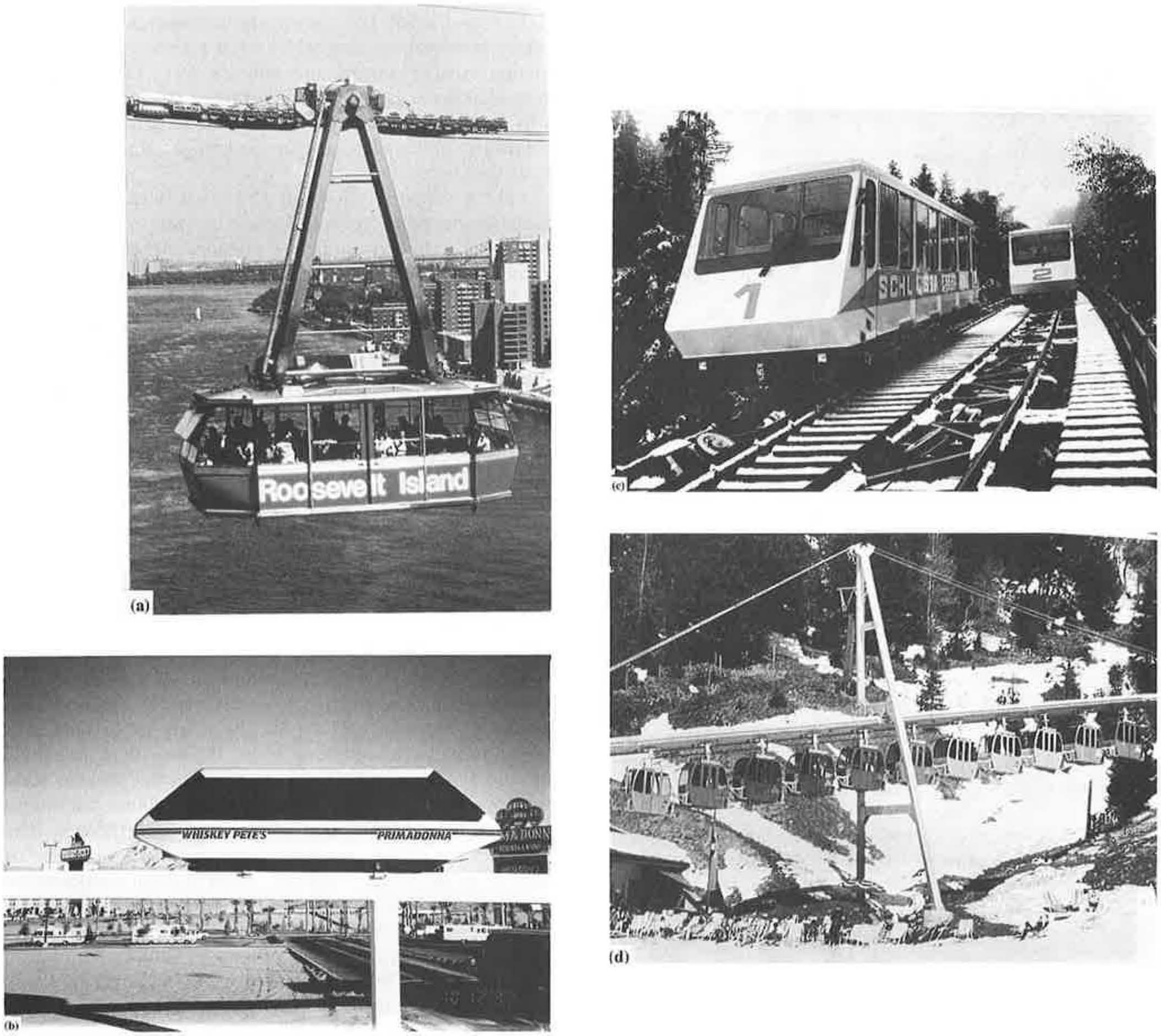


FIGURE 1 Reversible systems: *a*, suspended vehicle cable guideway tramway system (courtesy VSL); *b*, bottom-supported pneumatic tire shuttle system (courtesy VSL); *c*, bottom-supported steel wheel funicular system (courtesy Waagner-Biro); and *d*, rigid guideway suspended system (courtesy Waagner-Biro).

are typical. Multiple TUs run in each direction at the same time. Frequency of departure and wait time are not dependent on system length, operating velocity, or station dwell time.

Pulsed systems combine features of both reversible and continuous systems (Figure 3). Transport unit capacities are high and consist of a series of small vehicles assembled into trains. The haul rope does not reverse direction at the terminals. It moves in only one direction, turning the TUs around in the terminal. The cable is slowed or stopped to permit passenger loading in the terminals. Two or more TUs are attached to the cable. Every time a TU passes through a station, the cable is slowed or stopped. Because of this, hourly system capacity and wait time are a complex function of TU capacity, distance between stations, operating velocity, station dwell time, and the number of the TUs relative to the number of station platforms in the system. Maximum cruise velocity is 23 ft/sec. Pulsed systems are staging a comeback on European ski slopes. An advantage of the pulsed system over a reversible system is that more than two TUs can be operated at one time, thereby increasing frequency of departure and reducing wait time. An advantage over a continuous system is a much simpler mechanical requirement since vehicles do not need to be accelerated or decelerated independently of the haul rope or attached and detached. This simplified mechanism offers potentially lower capital and maintenance costs. However, station locations must be planned carefully. If they are not equally spaced, TUs will stop between stations. Also, capacities are relatively low.

The vehicle size categories used as the secondary variable for classifying type of service are based on the desire to dis-

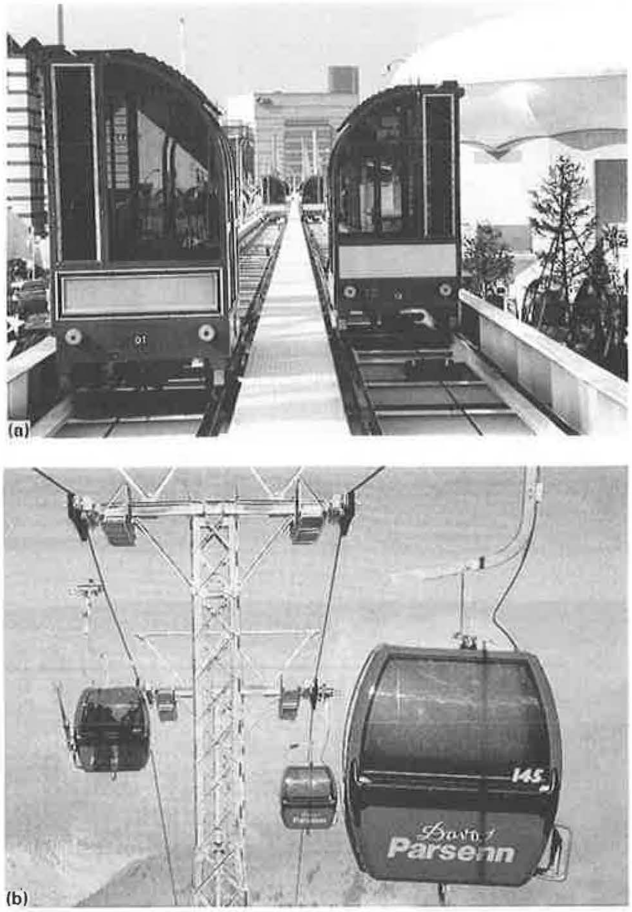


FIGURE 2 Continuous systems: *a*, bottom-supported system (courtesy Soule); *b*, suspended vehicle cable guideway gondola system (courtesy vonRoll).

FIGURE 3 Pulsed system (courtesy Waagner-Biro).

tinguish between technologies that offer smaller, more "personalized" vehicles from technologies that carry large numbers of people in single vehicles. The upper boundary of 14 passengers for small TUs was chosen to include the Soule SK system in the small vehicle category. The next boundary of 50 passengers per TU was chosen to distinguish between typical capacities for detachable and nondetachable TUs. The final boundary of 170 passengers was chosen to mark the upper boundary of reversible aerial tramway TU capacity among existing systems and indicate that TUs for existing funiculars have capacities much higher (there is no reason why larger capacity TUs could not be developed for aerial tramways, although passenger loading and unloading problems could occur).

Vehicle support technology defines a third classification variable. All cable technologies can be grouped into either a suspended or bottom-supported category. Among the existing suspended systems, all but two installations feature cable guideways. The cable guideway technologies have evolved to serve mountain transportation needs that involve steep gradients and chasms. Cable guideways leave a very small footprint and are relatively inexpensive. Rigid suspended guideways are more expensive to construct; the amount of additional expense depends on span length and load.

Among the systems with bottom-supported vehicles, three types of technology for the vehicle/guideway interface have been developed: levitation on a cushion of air, pneumatic tires, and steel wheel/rail. All use a guideway structure made of steel or concrete. The levitation and pneumatic tire technologies were developed for urban activity center markets and relatively flat terrain. The steel wheel/rail systems were developed for mountain applications and steep gradients. Many are placed in tunnels.

Table 1 also reveals combinations of types of service and vehicle support technology for which no systems presently are available. For example, the family of reversible systems is shown to be larger and cover more TU sizes than the family of continuous systems. Table 1 also indicates that no technology presently is being marketed that combines continuous service with vehicles suspended beneath a rigid guideway. The table reveals a lack of available systems featuring large or very large detachable vehicles, either bottom supported or suspended, and continuous service. Presently, one technology, the Soule SK, is being adapted to penetrate the boundary of this market area by means of a larger vehicle. Another of the technologies listed, the Poma 2000 operating in Laon, France, also is at the boundary of this market area.

GENERAL PERFORMANCE CAPABILITIES

As a generalization, given state-of-the-art design, the family of technologies fits a niche characterized by peak-hour demands of between 500 and 3,500 passengers per hour per direction per line, route lengths up to 3 mi, and three stations. Each of these values is dependent on the particular cable technology; some of the technologies could not achieve both the system length and capacity maximums simultaneously. However, these values can be achieved with off-the-shelf, presently available technology.

Figure 4 shows capacity versus system length characteristics for over 100 existing cable systems. Many of the gondola, tramway, and funicular systems represent ski area applications. The figure indicates that both funicular and gondola systems have been used to satisfy the simultaneous needs for high capacity and long travel distances over 10,000 ft; however, gondolas offer superior service because of their higher frequency. Pulsed systems have been used for long distances

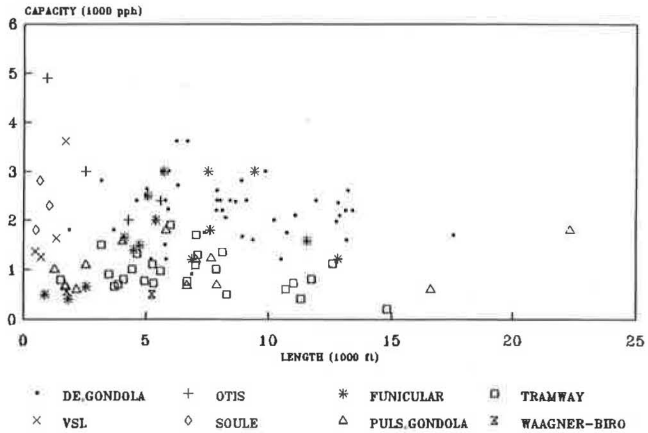


FIGURE 4 System length versus capacity.

combined with low passenger volumes. The bottom-supported technologies used in urban areas, as represented by the VSL, Otis, and Soule SK systems, tend to feature higher capacities and shorter system length of up to 5,600 ft.

Maximum velocities among the various classes of technology typically are as follows:

Class	*Maximum velocity (ft/sec)*
Reversible, bottom-supported	39.4
Reversible, suspended	32.8
Continuous, bottom-supported	18.0
Continuous, suspended	19.7

These speeds are adequate for many of the short distance applications for which cable technology is best suited. To exceed these velocities would require further research and development and, quite possibly, result in significant increases in the cost of system components. Considering cable technology in general, the upper limits of velocity are influenced by rope dynamics and safety. Higher speeds require more complicated design of equipment, such as acceleration and deceleration devices, bullwheels, and sheaves. The cost of design increases rapidly with increases in velocity.

Alignment capabilities vary from technology to technology. Suspended cable guideways are best suited to straight alignments. Horizontal curvature of suspended cable guideway systems can be achieved only with additional significant expenditure for land, structures, and mechanical systems. A common technique is to derope and decelerate the vehicle, shunt it around the horizontal curve on a rail at a reduced velocity, accelerate it back to haul rope speed, and reattach it to a second loop of cable for the next tangent. These actions are carried out in an angle or deflection station. However, the Waagner-Biro Suspended Reversible Monorail features a fixed guideway consisting of an I-beam approximately 0.92 ft by 0.92 ft, which lends itself easily to tight horizontal curves; radii as low as 328 ft have been used. The bottom-supported technologies all feature horizontal curvature, though minimum feasible radii vary from system to system. The minimum radius for the Otis system varies from 125 to 500 ft depending on the length of the vehicle; the Soule and VSL technologies can achieve 100-ft-radius curves. The Poma 2000 features a radius of 262 ft on unsuperelevated track and 131 ft on superelevated track. Horizontal radii for funicular systems tend to be large, however, because of the suspension systems on the vehicles and the lateral forces created by the rope and vehicle. Radii of horizontal curvature of existing funiculars range from 1,047 to 1,640 ft.

Ability to climb gradients varies dramatically among the systems. The suspended cable guideway systems easily can achieve gradients of 100 percent or more. The Waagner-Biro Suspended Reversible Monorail features a 37 percent gradient. Funiculars have been constructed with gradients exceeding 70 percent. Aside from the funiculars, other existing bottom-supported technologies have lower maximum gradients, partially because of vehicle floor design. When gradients exceed 15 percent, vehicle floors may have to be redesigned to accommodate passenger comfort needs. Otis installations feature gradients as high as 8 percent, though a 5 percent maximum is preferred. Soule claims that gradients up to 12 percent can be achieved, and VSL engineers state that 15 percent gradients can be designed. The Poma 2000 similarly claims to be capable of 15 percent gradients.

COSTS

Cable technology can offer a potential cost advantage because of several factors, all of which relate to the fact that the prime mover is stationary, rather than contained in each vehicle, and a cable is used to maintain vehicle position. This construction results in the potential for (a) less expensive and lighter vehicles as a result of the absence of individual vehicle-mounted propulsion units and computer guidance systems, and in most systems, absence of on-board heating and air conditioning units; (b) less expensive vehicles, resulting from lower cruise velocities, which reduce the costs of propulsion, braking, and suspension systems; (c) potentially lower guideway costs as a result of lighter vehicles and simpler guidance technologies; (d) less expensive power distribution requirements because of a lack of a need for a power rail in many systems; and (e) lower maintenance costs caused by simpler mechanical and electronic systems. Absence of a power rail also eliminates the risk of electrical fires in vehicles. Several suppliers of bottom-supported systems can provide a power rail if needed; they are necessary with the Otis technology to provide power for levitation of vehicles. Lack of heating and air conditioning in vehicles, however, can be a drawback during temperature extremes.

Availability of cost data is limited, making it difficult to compare the economics of the various cable technologies. Generalizations can be made, however. Guideway costs are low for the suspended cable technologies and involve only the support towers and cable. Most of the capital cost is associated with the terminals. For detachable gondolas, a rough rule of thumb is $5 to $9 million for a 1-mi system. A reversible tramway could be somewhat more expensive because of more massive terminals and machinery; in one feasibility study conducted nearly 10 years ago the cost of a 4,000-ft system was estimated at over $10 million. Most existing funicular systems have been built in tunnels and thus involve tunneling costs of between $800 and $1,300 per ft if boring conditions are good. Installed costs have been estimated as $1,500 to $2,500 per linear foot, or about $8 million to $13 million per mi for funiculars. Otis officials suggest that a 1-mi levitated system including civil works would cost around $14 million. Soule officials estimate that a 0.5-mi system would cost $4 million to $8 million exclusive of civil works. VSL reports that the 1980 cost of a 1,300-ft system was $3 million. Thus, a crude estimate of costs for a 1-mi system would be approximately $10 million plus or minus several million dollars depending on site characteristics and the particular technology.

APPLICATION POTENTIAL

Potential applications exist for several basic types of systems, including airports, feeders to regional rapid transit, downtown circulators, feeders to remote parking, internal circulation in large developments, and leisure facilities. The technology in its present form is not suited for line-haul service, for which buses, advanced light rail, rapid transit, and conventional rail systems are more appropriate. Also, system expansion can be costly and difficult unless anticipated and planned for during initial design.

An important capability of the suspended cable systems is their ability to span long distances without the need for supporting structures. Thus, they can inexpensively span rivers, highway interchanges, rail yards, and low structures. They are an inexpensive means of providing extra capacity across rivers and linking downtowns with redevelopment projects on the opposite side of a river. A second unique capability of aerial cable systems is their ability to ascend gradients as high as 100 percent. This enables them to provide people mover functions in environments in which no other technology would be satisfactory. A primary example is mountainside transportation or combinations involving rivers and mountainsides. Examples of this type of application can be found around the world in urban areas. Frequently, they involve leisure facilities that are major regional attractions and contribute to the local economy. An example is the reversible aerial tramway that ascends Sugarloaf Mountain in Rio de Janeiro.

A potential drawback of suspended cable guideway systems is the sense of insecurity they may generate among users. The experience of hanging from a single wire rope in a vehicle undergoing lateral sway and vertical oscillations can be frightening to those unused to it. Although danger is negligible, perceptions may suggest the opposite. The pervasiveness of this apprehension in American culture is unknown. Although this apprehension probably decreases with exposure, only those individuals who ski have the opportunity to become familiar with suspended cable systems. However, gondola systems that feature two or more haul cables have been developed (*2*). Multiple-haul cables increase the stability of the vehicles and produce a better ride quality. Bottom-supported systems, in contrast, project a strong sense of security. Also, they are less subject to service interruptions caused by weather conditions. Suspended systems, for example, must be shut down during high winds and electrical storms.

Airport Applications

For airport systems featuring terminal configurations that require only simple two-station shuttles, cable is appropriate. Given the short distances and lack of need for multiple station stops, cable technology may be able to provide nearly the same level of service as that of self-propelled vehicles. In fact, cable systems have begun to find applications in Japan, where one is being installed by Otis at Narita.

Feeders to Regional Transit

The use of people movers as feeders, an option that has been neglected in the United States, could encourage use of rail rapid transit and regional rail systems. Cable systems are being implemented in France by Soule for this purpose. A cable feeder line could connect a land use that generates a large number of trip ends (such as a hospital, university, government buildings, or an office center) and a transit/rail station that lies within about 1 mi. In the United States, one example of a cable system feeder can be found at Roosevelt Island, New York, where a reversible aerial tramway connects the island with a terminal in Manhattan. Passengers can transfer to buses at the terminal (*3*).

Downtown Circulators

Some downtown people movers are planned as one- or two-way loops that serve multiple stops. Cable technology may not be as well suited as self-propelled people movers for this type of configuration. However, configurations that can be planned as two or more separate lines that cross each other or touch at their endpoints might be suitable candidates for cable technology. Examples of proposals of the type that featured gondola systems include Kansas City, Mo. (*4*), and Santa Cruz, Calif., where a pulsed system was proposed (*5*). A bottom-supported reversible system has been constructed to connect Harbour Island with downtown Tampa, Fla. (*6*). A gondola system to access the Cincinnati CBD has been studied (*7*), as well as a reversible aerial tramway to connect Detroit, Mich., with Canada across the Detroit River (*8*). The difficulty associated with future expansion of cable systems, as mentioned previously, could be a potential drawback for their use as downtown circulators.

Feeders to Remote Parking

Another neglected option is the feeder from a downtown area to remote parking at the fringe of the CBD. A reversible cable system to serve this purpose has been studied for Pittsburgh, Pa. (*9*). A gondola system to connect Denver's Auraria Higher Education Center with remote parking facilities located at Mile High Stadium also was studied (*10*). Additional opportunities for remote parking feeders exist around freeway interchanges located at the periphery of the CBD. Airports may represent opportunities for connections between terminals and parking lots or rental car lots. Feeder facilities also may serve leisure centers.

Internal Circulation in Large Developments

Internal circulation systems in office complexes, shopping centers, residential developments, and mixed land use developments can enhance land values under the right conditions. The internal circulator also may connect to a regional transit system or remote parking and serve as a feeder. Large office parks present an opportunity for the use of people movers to eliminate the need for parking areas immediately adjacent to buildings. Parking lots can be located toward the periphery of the site, and the interior can be preserved for pedestrian walkways and green areas. This type of planning can enhance the appearance and environmental quality of the site and help achieve aesthetic objectives. Developments that feature vertical elevators in buildings may be potential candidates for horizontal people movers to link buildings together and to parking facilities. Examples of this type of application have occurred primarily in leisure facilities.

Leisure Facilities

Leisure facilities consist of public parks, theme parks, hotel/convention centers, resorts, and expositions. Systems serving these areas may provide internal circulation or link parking areas with major attractions. Most of the existing detachable and pulsed gondolas, reversible aerial tramways, and funiculars presently serve ski areas. Bottom-supported reversible systems also have been constructed at three hotel/casinos in Nevada and one in the Republic of Bophuthatswana in South Africa. Cable technology has been integrated architecturally in the hotel/casino applications. Terminals of the hotel/casinos are located adjacent to gaming rooms but could just as easily be located adjacent to lobbies. A bottom-supported reversible system is under design for the J. Paul Getty Museum in Los Angeles. Bottom-supported continuous systems have been employed at Expo 86 in Vancouver, B.C., the Yokohama Exotic Showcase Centennial, in Japan, and the Paris-Nord Exhibition Park in France. The Mississippi Aerial River Transit System, or MART, was a detachable gondola constructed to link the New Orleans World's Fair with remote parking on the opposite side of the Mississippi River (*11*).

CONCLUSIONS

Despite the relatively small number of existing urban applications, suppliers of cable technology are continuing to make design improvements that could expand market potential. Improvements include guideway design, a wider range of TU sizes, innovations in suspension, and adaptation of state-of-the-art command and control technology. On many recent bottom-supported reversible systems, the user may be unaware that the vehicle is passive and being propelled by a cable rather than by on-board electric motors. In terms of vehicle departure frequency, the continuous systems can provide a level of service that approaches that of personal rapid transit. Eight- or 9-sec headways are common for systems with four- to six-passenger vehicles. With vehicles this small and with headways this short, the development of an off-line station capability would result in personal rapid transit. One supplier has proposed this, but the concept has not yet been developed and tested (*12*).

Technological constraints vary markedly among the systems. The strongest potential market for cable systems may be new developments, where the numbers and locations of stations and the transportation system can be planned simultaneously with major buildings. This type of planning would enable accommodation of any of the technological constraints of cable systems. Pulsed technology could prove highly cost-effective under the right circumstances. Although station spacing is critical to the success of pulsed systems, it easily could be taken into consideration during the planning of new developments.

Available cost data are insufficient to draw any firm conclusions about the price competitiveness of cable technology versus self-propelled technology. Available data suggest that cable may have an advantage in terms of guideway and vehicle cost. Maintenance costs for reversible and pulsed systems should be low. Individuals trained to maintain elevators conceivably could be trained to maintain cable systems.

ACKNOWLEDGMENTS

This research was supported by a grant from the U.S. Department of Transportation, University Transportation Centers Program; and the International Organization for Transportation by Rope, North American Continental Section.

REFERENCES

1. T. J. McGean and C. P. Elms. Market for AGT and Its Implications For Needed RA&D. In *Automated People Movers—Engineering and Management in Major Activity Centers. Proc. 1st International Conference on Automated People Movers* (E. S. Neumann and M. V. A. Bondada, eds.), Miami, Fla., ASCE, New York, 1985, pp. 13–22.
2. DMC or DMC? *International Aerial Lift Review*, Vol. 1, 1989, pp. 35–39.
3. N. D. Lea and Associates, Inc. *Roosevelt Island Tramway System Assessment*. U.S. Department of Transportation, Urban Mass Transportation Administration, 1989.
4. J. Fletcher and J. K. Bunch. Potential for Urban Applications of Multi-Car Tramways. In *Automated People Movers II. Proc., 2nd International Conference on Automated People Movers* (M. V. A. Bondada, W. J. Sproule, and E. S. Neumann, eds.), Miami, Fla., ASCE, New York, 1989, pp. 882–888.
5. T. J. McGean, G. B. Douglas, B. Von Allmen, and P. Douglas. *Santa Cruz Fixed Guideway Project, Urban Corridor System Planning Study*. Santa Cruz Metropolitan Transit District, Santa Cruz, Calif., 1989.
6. Lea, Elliott, McGean & Co. *Mt. Adams Aerial Transportation System Study*. Final Report. Cincinnati, Ohio, 1985.
7. J. R. Carrick. The People Mover at Harbour Island. In *Automated People Movers II. Proc., 2nd International Conference on Automated People Movers* (M. V. A. Bondada, W. J. Sproule, and E. S. Neumann, eds.), Miami, Fla., ASCE, New York, 1989, pp. 755–764.
8. Smith Hinchman & Grylls, Gannett Fleming Corddry and Carpenter of Michigan, Inc., and others, *Feasibility Study-Detroit/Windsor Aerial Tramway*. Final Report. Detroit, Mich., 1979.
9. Gannett Fleming Transportation Engineers, Inc. *Detailed Description of Final Horizontal Alternatives*. Technical Memorandum. Department of City Planning, City of Pittsburgh, Aug. 1984.
10. A. Doppelmayr and J. Fletcher. Denver Auraria People Mover. In *Automated People Movers—Engineering and Management in Major Activity Centers. Proc., 1st International Conference on Automated People Movers* (E. S. Neumann and M. V. A. Bondada, eds.), Miami, Fla., ASCE, New York, 1985, pp. 452–463.

11. J. K. Bunch, J. Fletcher and S. Bonasso. Application of a Detachable Gondola Ropeway in an Urban Transport Environment: New Orleans, La. In *Automated People Movers—Engineering and Management in Major Activity Centers. Proc., 1st International Conference on Automated People Movers* (E. S. Neumann and M. V. A. Bondada, eds.), Miami, Fla., ASCE, New York, 1985, pp. 442–451.

12. N. Reidl and F. Klopf. An Urban Transport Alternative—C-Bahn. In *Automated People Movers II. Proc., 2nd International Conference on Automated People Movers* (M. V. A. Bondada, W. J. Sproule and E. S. Neumann, eds.), Miami, Fla., ASCE, New York, 1989, pp. 941–953.

Publication of this paper sponsored by Committee on New Transportation Systems and Technology.

Personal Rapid Transit: Developing a New Mode of Public Transportation

Mark C. Ahlheim

The development of the Regional Transportation Authority's (RTA's) Personal Rapid Transit (PRT) Project since the project was announced in April 1990 is chronicled and the decision-making process that led to its initial formulation is explored. PRT's possible application in Northeastern Illinois, the growth in Chicago's suburbs, and the changes in Chicago's commuting patterns that have triggered RTA's examination of a new transit technology are described. In 1950, Chicago's suburbs had about 20 of every 100 jobs in the Northeastern Illinois region. Today, they account for almost 60 percent of the jobs, and their share is growing. RTA's PRT Project is a response to these fundamental changes to the Northeastern Illinois suburban landscape. The key elements of the PRT Project to date include (a) a multiphased approach with decision points at the end of each phase; (b) competitive system designs to foster competition; (c) drawing new technology out of the private sector by identifying new markets and giving generous public exposure; and (d) hedging risk by sharing in the ownership of new intellectual property and by developing partnerships with private, and other public, entities. The PRT site selection process has identified four communities that measure best against a list of attributes possessed by an ideal PRT community. All four have thus far met RTA's requirements for complementing the existing regional transit system and for generating local support.

"Chicago's booming suburbs are hurtling down a road of riches that dead ends in gridlock" (*1*). So stated a February 1990 series of *Chicago Tribune* articles on traffic congestion in Chicago's suburbs. Two months later Gayle M. Franzen, chairman of the Northeastern Illinois Regional Transportation Authority (RTA), announced RTA's Personal Rapid Transit (PRT) Project as a possible first step in the evolution of a new mode of public transportation for suburbia. "We have reached a crossroads in the public transportation industry," Franzen said on the day the project was announced. "Suburban growth patterns have outstripped our capability to serve new markets with only traditional forms of transit" (*2*).

This paper chronicles the development of RTA's PRT Project since that announcement, explores the decision-making process that led to its initial formulation, describes PRT's possible application in Northeastern Illinois, and describes the growth in Chicago's suburbs and the changes in Chicago's commuting patterns that have triggered RTA's examination of a new transit technology.

GRIDLOCK IN SUBURBIA

Transportation has always been the lever on economic development and prosperity, and the development of Chicago's suburbs during the past four decades are a case in point. In 1950, Chicago's suburbs had about 20 of every 100 jobs in the Northeastern Illinois region. Today, they account for almost 60 percent of the jobs, and the Northeastern Illinois Planning Commission predicts that their share will rise to 65 percent by the year 2010. More than half of all Chicago area workers currently commute from suburb to suburb, whereas fewer than 15 percent make the traditional commute from suburbs to city, according to the Chicago Area Transportation Study. And in the morning, outbound traffic on two of Chicago's busiest radial expressways—the Kennedy and the Eisenhower—are often higher than inbound volumes.

This change in travel patterns is having a clear impact on the form of the suburban landscape. Schaumburg, Illinois, for example, once a remote farm town 29 mi northwest of Chicago's Loop, has become a community with 8 million ft^2 of office space, just 2 million ft^2 less than downtown Milwaukee, Wisconsin. The Sears, Roebuck and Co.'s recent decision to move its merchandise group headquarters, and more than 5,000 Sears employees, from the Sears Tower in downtown Chicago to a 786-acre site in Hoffman Estates, Illinois—a Chicago suburb even farther away from Chicago's downtown—illustrates this migration of businesses to the suburbs and the concomitant change in regional travel patterns.

In short, the rising number of Chicagoans and residents of the inner suburbs driving to jobs in the outer suburbs is leading a shift in economic development in the six-county metropolitan region, but it is also bringing with it increased suburban congestion. Consequently, the mobility, prosperity, and quality of life of the suburbs—precisely those attributes that attracted first residents, retailers, and now businesses to suburban locales—are ironically being threatened, jeopardizing the economic future of the entire region. RTA's PRT Project is a response to these fundamental changes to the suburban landscape and is part of a larger, more comprehensive technology development and capital program whose aim is to address these vexing problems.

RTA'S TECHNOLOGY PROGRAM

The Regional Transportation Authority was established in 1974 on approval of a referendum in the six-county Northeastern Illinois region. RTA is a special unit of local government, a body politic, political subdivision, and municipal corporation of the state of Illinois. Initially, RTA provided financial assistance to the then-existing public transportation carriers.

Regional Transportation Authority, One North Dearborn, Suite 1100, Chicago, Ill. 60602.

RTA also entered into purchase-of-service agreements with private railroad companies and private and public bus companies. As a number of carriers discontinued service, RTA temporarily became engaged in direct operations.

In 1983, the RTA Act was amended to make substantial changes in the organization and funding of RTA and its operations. All operating responsibilities were placed in three "Service Boards": the Chicago Transit Authority (CTA) and two RTA operating divisions—Metra (the commuter rail division) and Pace (the suburban bus division)—each having its own independent board of directors. RTA was given increased power and responsibility to supervise the budgets and financial condition of the CTA, Metra, and Pace. RTA's responsibilities for fiscal and policy oversight of public transportation services in the region were also increased.

The 1983 Regional Transportation Authority Act also gave RTA the responsibility to conduct the region's research and development. In particular, the act calls for RTA to study public transportation problems and developments; encourage experimentation in developing new public transportation technology, financing methods, and management procedures; and conduct, in cooperation with other public and private agencies, studies and demonstration and development projects to test and develop methods for improving public transportation, for reducing its cost to users, or for increasing its public use (*3*).

In the past year, RTA has formalized its research and development effort by forming a capital program and technology division. This division, headed by Marc A. Hillier, directs the PRT effort and tries to identify and develop other new technologies that promise increasing efficiency and effectiveness of the region's public transportation services.

RTA'S PRT PROJECT

RTA's PRT Project is being conducted in three phases. They are as follows:

Phase I: System Design

Develop a system design that would meet the RTA definition of PRT and RTA's goals for personal transit for the public. The intended outcome of this phase is a system design of such quality and promise that RTA can confidently proceed with Phase II. The system design must be safe and reliable and must provide evidence that in subsequent phases it can be developed, economically constructed and maintained, and deployed as a successful transit demonstration project.

Phase II: Development and Test

Develop hardware, including prototype guideway sections and vehicles, and all operational control and communication software for testing at a test site. Testing would begin with individual component testing and would proceed to the extent necessary to determine the desirability of proceeding to Phase III. It is anticipated that this phase would conclude with an extensive indoor and outdoor test of a completely integrated PRT system.

Phase III: Demonstration Site Deployment

Construct and operate during Phase III a 2- to 4-mi demonstration PRT system in a suburban Chicago community.

The system design work started in March 1991 and was scheduled for completion in March 1992. The Phase I work is being done by two competing system designers: Intamin AG (Wollerau, Switzerland) and Stone & Webster Engineering Corporation (Boston, Massachusetts). Each contract is for $1.5 million. At the completion of Phase I, if RTA is satisfied with the progress of the system designs, comfortable with the financial arrangements for future phases, and convinced that PRT will increase the public's use of public transportation and have a positive impact on the region's productivity and mobility, RTA would select one of the two system designs for further development. A technical support team—Custom Engineering, Inc. (CEI)—was hired to aid in the technical evaluation of these competing system designs and was instrumental in the creation of the project's form and content. This team is led by Carlos deMoraes, CEI president.

Of the original 22 communities expressing interest in the project, four suburban Chicago communities have demonstrated that they offer the most potential for a successful PRT deployment and are currently competing to host the initial demonstration system. Ridership demand estimations were scheduled for completion in February 1992 to gauge the ridership potential at each of these proposed sites. The goals of the PRT Project are manifold:

1. To conceptualize a new mode of public transport, one that combines right-of-way, technology, and type-of-service in nontraditional, creative, and unique ways;
2. To develop this new mode and successfully demonstrate its applicability to markets in the Northeastern Illinois region;
3. To show that this new mode is safe, reliable, and efficient, and is an effective complement to existing transit modes; and
4. To provide strong evidence that this new mode may be deployed with a minimum of disruption to the community. Disruption is minimized by civil works that may be constructed relatively quickly and inexpensively, by environmental impacts during operation that are acceptable to the community, and by guideways that are aesthetically unobtrusive and easy to maintain.

For the purpose of this demonstration project, RTA has defined PRT as follows:

- Fully automated
- Two- to five-passenger vehicles, all seated;
- One-way guideways;
- All stations off line and free standing;
- Minimum mainline headway of 5 sec at demonstration system start-up;
- Capability to meet needs of a large network;
- Wait time for vehicle 3 min or less;

- Goods movement capability;
- Service that is accessible to disabled and mobility-impaired passengers; and
- System availability goal at least 99.7 percent within 6 months of start of demonstration service.

DEVELOPING A NEW MODE OF PUBLIC TRANSPORTATION

Having the statutory obligation to do research and development is one thing; developing a mode of public transportation that according to the RTA definition of PRT does not yet exist is quite another. Lacking the staff expertise and wherewithal to examine this technology on its own, and faced with approximately one-third of the region's $16 billion transit infrastructure in desperate need of repair, RTA had to structure a PRT research and development program that extracted new technology from the private sector, identified viable markets (if any) for a mode of transportation that does not yet exist, minimized the risk associated with public funding, and minimized the diversion of capital dollars from a badly needed, and highly visible, capital program.

Minimizing Risk

There is some risk involved in any research and development effort. No research and development project is assured of success. And public sector officials are particularly prone to charges of unnecessarily risking public dollars on projects that promise highly visible, yet uncertain, payoffs to society. RTA has therefore tried to structure the PRT program so that the financial risk associated with this project—a risk that is often magnified in the public sector because of the competition for scarce public dollars, particularly in this case—is limited.

Structuring the PRT research and development effort was indeed easier given the general support of Chairman Franzen and the RTA board. The Board has been willing to start a program of innovation that is atypical of a public agency. Indicative of this attitude is Chairman Franzen's remarks (*2*) on the day the PRT Project was announced:

> I think that too often public agents refuse to recognize innovation based simply upon institutional biases. There is a hesitancy to pursue technologies such as PRT only because it has never been done before. We at RTA think differently. If a technology is viable, then we feel it is our obligation to experiment to see if it can indeed provide answers to our problems. We must look beyond the restraints of our industry and explore. It is more than our statutory obligation, it is our public responsibility.

Because of the dispersed travel demands characteristic of Chicago suburban development and travel and the dramatic improvements during the last decade in solid-state controller technology and microprocessor controls, PRT seemed, at first blush, to be more applicable to suburban travel and more feasible than what staff originally expected. The PRT technology was so new and exciting that the immediate temptation was to run quickly to its development and implementation. Because staff members had also visited with Morgantown PRT officials and learned the difficulties Morgantown PRT experienced in their quick 22-month development effort they had to temper their excitement with the need to proceed responsibly and with caution to ensure that the public was well served.

This requirement led to the project being broken into phases. Each phase is structured with a decision point at its conclusion: Is it prudent to commit more public funds for PRT development and proceed with the next phase, or are the results to date too discouraging, and projects costs too excessive, to merit further public funding? The project therefore has built-in mechanisms that limit the exposure of public funds and allow for public scrutiny and an explicit examination of the benefits and costs of proceeding.

Risk was further mitigated when contracts with the system designers were negotiated. Each contract includes language that gives RTA the possibility of jointly owning all intellectual property (patent, copyright, trade secret, trademark, or other intellectual property rights) developed as part of this contract or as part of future phase work. Moreover, as a precedent to proceeding with any future phase work, the selected system designer may be required to agree on an arrangement by which RTA would earn a royalty on fees earned by the system designer for the design and development of any other PRT system.

This unique financing arrangement follows from RTA's statutory obligation to also develop new financing methods and follows from the venture capital mode of financing private enterprises. A venture capitalist expects to be rewarded for the risk involved in fronting the money to finance an unproven, and perhaps risky, new venture. Similarly, RTA structured the PRT agreements so it could possibly recoup its initial investment and potentially receive a revenue stream for many years to come, one that could be used to examine other promising public transportation technologies or for badly needed capital improvements. A key difference, however, is that RTA in this case assumed additional risk other than simply a financial one. Whereas a venture capitalist may also lend some managerial expertise to the initial start-up effort for a product or service aimed at a particular market segment—a segment that is often fairly well defined—RTA was also responsible for identifying and cultivating travel markets that neither RTA nor the system designers even were sure existed. In effect, RTA's call for community participation, and the creation of evaluation guidelines that described an ideal PRT community, created a marketplace of potential PRT sites ready for the system designer's service that heretofore had not existed.

Extracting New Technology from Private Sector

Based on conversations with numerous corporate entities that may have an interest in developing PRT, RTA thought that the PRT Project would have to be structured in a way that would attract firms with the human and financial resources to carry this project beyond its initial stages. The project also had to be attractively enough packaged so that the private sector would be willing to risk some of their own capital if that was necessary to complete the initial phase.

There were concerns expressed over the cost associated with developing a PRT system, and there was uncertainty about the existence of a transit market for this product. After all, if markets did exist, why hadn't the private sector already developed, and marketed, a PRT system as they had successfully done with other automated systems? Quite honestly, it was unclear how much the system design work would cost to complete, or how many, if any, responsive proposals would be submitted in response to the initial request for PRT proposals. It was clear that this research and development project would require an innovative structure to attract firms with appropriate capabilities and adequate resources.

A key decision was made early to structure the project so that there would be competitive system designs. Opening the first phase to two different firms developing independent system designs served three primary purposes: (a) it allowed RTA to see a range of system design choices and select the one design that was most appropriate for the Northeastern Illinois region; (b) it created an element of direct competition that RTA hoped would result in system designers being more responsive to RTA's needs and desires for Phase I as well as for Phase II; and (c) it would open the door for more firms to initially participate, to gain a measure of notoriety, move down the PRT learning curve, and be poised to enter the PRT marketplace even if not selected for a second phase.

Conducting a parallel search and competition among Chicago's suburban communities to host the initial PRT demonstration was another key element of the project structure. RTA had believed that developing competing PRT system designs was not enough. A process to identify viable markets had to be developed to entice private participation and to ensure that there was a user for the technology developed. The very act of communities competing for the initial demonstration, and acknowledging a need for PRT, meant that the system designers would not have to undertake a lengthy, and perhaps expensive, market identification effort on their own and that they could still approach competing communities with ready-made PRT plans if not selected for Phase II work. The competitive nature of the process would mean that communities would be most apt to submit site proposals that met RTA guidelines for personal transit for the public. Hence, the RTA created a parallel competitive PRT site selection process that is described in further detail in the next section.

One final element of the project used to entice private participation was to set aside a large portion of the Phase I work plan for public presentations and communication. The Phase I work scope includes two-dimensional and three-dimensional computer simulations; scale models of PRT stations, vehicles, and guideways; and four community presentations that allow system designers to illustrate how their system would look, demonstrate how it could be used, and in general show off their system designs. The process gives generous public exposure to each system design and gives the system designers excellent opportunities to build working relationships with community representatives.

Public/Public and Public/Private Partnerships

The seed money for PRT development has thus far been solely provided by RTA. But the process has been structured so the cost of future phases, if any, will be shared by other public or private entities, or both. Given that RTA's current priority is rebuilding the region's transit infrastructure, the success of the PRT research and development effort will ultimately depend on finding other sources of financing and in-kind support to bear the major burden of additional program costs.

As part of the Phase I work scope, system designers are required to describe their exact contributions, including those of any private partners, for their planned Phase II work program. The overall cost, financing arrangements, and schedule for Phase II must also be presented. RTA's present goal for a second phase is to develop as much private financing as possible. If not enough is found to cover the total development and testing costs for Phase II, RTA will seek partnerships with other public agencies or private entities to co-sponsor this work.

For Phase III, RTA has said that any community selected for a demonstration system should acquire and provide all right-of-way necessary for PRT deployment. Furthermore, RTA has stated that an ideal demonstration site would offer the potential for a partnership among RTA, local governments, and developers with the objective of exploring creative financing arrangements, integrating PRT designs with existing or proposed development, mitigating construction and operating constraints, marketing a strong, positive image of the system, and supporting and promoting PRT ridership.

A unique partnership between RTA and other transit agencies has also been forged to review the operational aspects of the two system designs. Personnel from B.C. Transit, Detroit Transportation Corporation, and Bay Area Rapid Transit have served on a PRT Advisory Group to review and comment on the system design from the start of the project. These individuals have considerable experience with day-to-day operation of automated transit systems, and their critiques focus on practical operational issues that normally get overlooked at this stage of the design process. Two other members of the advisory group have special expertise to advise the RTA on disability design and ridership estimations. The following are the individuals who have served in this group: Clyde Hayes, Operations Director, British Columbia Rapid Transit Co., Ltd.; William McDowell, formerly Executive Director, Detroit Transportation Corporation; James King Jr., Manager, Reliability Engineering, Bay Area Rapid Transit District; Alan Hewson, Manager, Special Services, Chicago Transit Authority; and David Boyce, Director, Urban Transportation Center, University of Illinois at Chicago.

RTA has also formed a group of service board representatives. Members of the CTA, Metra, and Pace were directly involved with the system designer selection process and continue to be important sources of advice and information during site evaluation and selection activities. Their input regarding new transit initiatives that may potentially complement, or complete with, PRT service and their knowledge of changing suburban development and travel patterns are an increasingly important part of the process.

PRT SITE SELECTION AND POSSIBLE PRT APPLICATIONS

Site Selection Process

RTA began the site selection process with a call for interest to all 265 Northeastern Illinois suburban communities. Of those, 22 communities expressed initial interest in the PRT

Project subject to reviewing a draft of request for PRT site proposals (RFP) that was forwarded to these communities immediately thereafter. An informational meeting was held with the 22 communities, and their comments were incorporated into the RFP. Six suburban Chicago communities—Addison, Deerfield, Lisle, Naperville, Rosemont, and Schaumburg—eventually submitted formal PRT Site Proposals. After an evaluation of the written materials, and after community presentations and site visits, RTA decided that Deerfield, Lisle, Rosemont, and Schaumburg should remain as candidate deployment sites and participate in the next stage of site selection activities.

The PRT site selection process was governed by three guiding principles that were used as evaluation criteria (*4*):

1. *Ridership potential.* PRT ideally will be located where a sufficient number and variety of work and nonwork destinations exist to generate stable riderships throughout the day without extreme single-point loading. The site should complement the regional transportation system by tying in with other transit service and with parking and highways, as appropriate. A site within a major multiuse complex in which PRT would serve as an internal distribution and circulation system in preference to the automobile would be attractive.

Chairman Franzen articulated early on that it was essential for PRT to connect to CTA, Metra, or Pace service to aid in serving a longer regional trip. Because any initial system would be no larger than perhaps 2 to 4 mi, it was important that PRT go beyond serving a simple internal circulation function and serve regional trips where PRT, in concert with bus or rail service, would be preferable to the automobile.

2. *Constructibility*. The site must have the requisite space to construct the system and should offer a setting which elevated guideways and fully accessible stations can be integrated within existing and future development without conflicting with community open space, historic preservation, or environmental protection objectives. The site should present realistic construction challenges without major cost risks (e.g., utility relocation, code restrictions, and architectural or physical barriers). The site must provide for the necessary PRT maintenance facility. The potential for cost-effective expansion beyond the boundaries of the initial demonstration system will also be an important consideration.

Because RTA had little idea what PRT would cost to construct, the RFP asked each community to show a 2-, 4-, and 6-mi PRT system on its proposed site plan. In response, some communities proposed up to 11-mi systems with expansions beyond the conceptual site plan to show possible PRT extensions.

3. *Local commitment*. The successful demonstration of PRT will best be achieved in partnership with local private and public interests committed to its success. PRT must be integrated into existing or planned development and marketed as an attractive alternative to the automobile. Creative approaches on how to structure this partnership will receive high priority in the evaluation of competing sites.

Chairman Franzen has also said that the NIMBY (not in my back yard) syndrome would guide the site selection process. RTA would not put PRT where it was not wanted, and the RFP clearly stated that an ideal PRT community would have broad and vigorous support of local community groups and the general populace.

Rather than ask the communities to simply state the merits and superior qualities of their proposed sites, the RFP asked each community to compare their conceptual plans to an ideal site. The creation of an ideal site set a standard for site evaluation and clearly expressed to the communities which site attributes RTA felt were most important to achieving a successful demonstration system deployment.

The communities were also told that the submittal of a site proposal was only the first part of a longer process. RTA recognized that the attractiveness of some proposed sites may depend on specified, yet uncertain, future development, and some sites may propose plans and commitments that have not yet had time for local community review and support. The objective at this point of the process was to simply narrow the group of interested communities to those sites that measured favorably against the stated evaluation criteria and possessed the characteristics necessary to define a Phase I "composite site." Selected communities would be subject to a final and more rigorous evaluation when, and if, RTA decided to proceed with Phase II.

To digress for a moment, the composite site is a hypothetical site consisting of the most limiting features (e.g., maximum span between columns, minimum turning radius, etc.) constraining the PRT design at the locations proposed by each community. The composite site plan and models are being used to evaluate the capabilities and robustness of each of the competing system designs.

Possible PRT Community Sites

The proposed expanded PRT site plans for Deerfield, Lisle, Rosemont, and Schaumburg are shown in Figures 1–4, respectively. The following are the PRT community representatives: Kent S. Street, Assistant to the Manager, Village of Deerfield; Mary Lou Kalsted, Assistant Village Manager, Village of Lisle; Terrance McCabe, Village Attorney, Village of Rosemont; and Thomas J. Dabareiner, Transportation Planner, Village of Schaumburg.

All the sites complement CTA, Metra, or Pace service and all have core routes that have the potential to serve a longer regional trip. A summary of each proposed site plan follows.

Deerfield PRT Site

Deerfield proposes a core PRT system of approximately 2.75 mi long with four stations in this primary loop. The system would directly connect with a proposed Metra Milwaukee station at Lake-Cook Road and would service office and commercial centers in the surrounding area. These destinations include Matas-Corporate 500, Deerbrook Shopping Center, Lake-Cook Plaza, and Underwriters' Laboratories. The PRT maintenance and administration building would be located adjacent to the parcel proposed for the joint Metra-PRT station construction.

Deerfield proposes two major expansions to the initial demonstration system—one to the west and one to the east. The western expansion consists of a PRT loop that accesses major employment centers on and adjacent to Lake-Cook Road and the Tollway Spur in Deerfield and Northbrook. This expansion, approximately 5.7 mi in length, would use Tollway right-

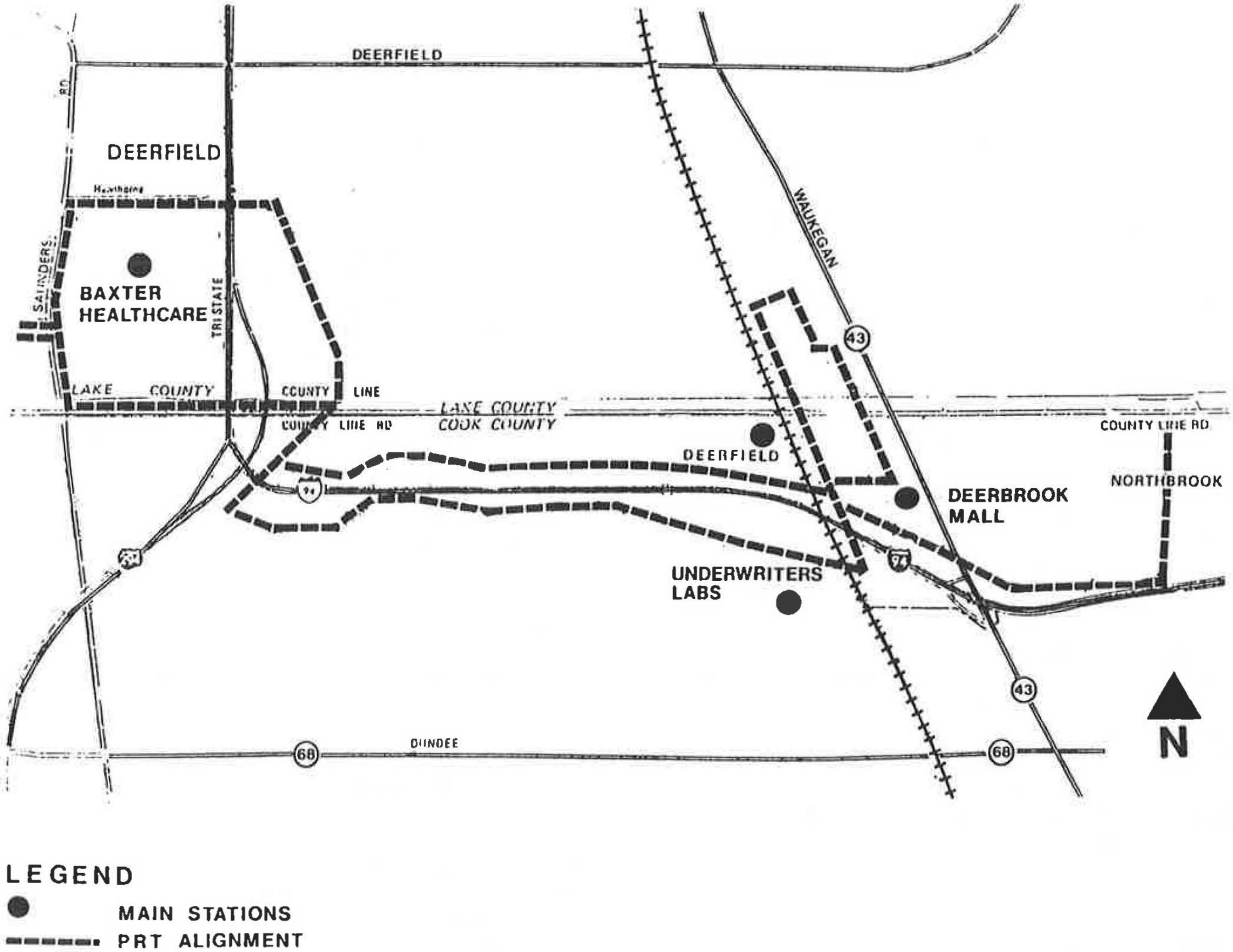


FIGURE 1 Proposed site plan for Deerfield.

of-way to service employment centers along both sides of the Tollway Spur, including the Sky Harbor industrial complex to the south, and the Lake Cook Office Center, Teradyne complex, and Arbor Lake Development to the north. This same expansion would also serve the Hyatt-Deerfield, Walgreen Company property, Baxter Healthcare, and Homart/Dean Witter development further north and west.

An expansion to the east would provide access to Northbrook Court, which is located approximately 1 mi from the proposed Lake-Cook Metra station. This major retail shopping center would be accessed along the northern edge of the Tollway Spur right-of-way. The distance of this PRT loop is approximately 2.6 mi.

Lisle PRT Site

Lisle proposes a core route approximately 2.5 mi in length, extending north from the Metra Burlington Northern train station. It serves downtown Lisle, portions of three office/research developments, the Hyatt-Lisle hotel, and a full-service automobile dealership complex. The project site is generally bounded by the Metra BN line to the south, the East-West Tollway to the north, Route 53 to the west, and the Corporetum property to the east. Major traffic generators include the Arboretum Lakes development, the Corporetum office campus development, the Hyatt-Lisle, and the Lisle Auto Plaza car dealerships. The initial demonstration system could accommodate 7 to 10 stations.

Lisle has also identified three primary expansions and seven other potential extensions to the initial system. The first primary extension extends the demonstration system farther west to serve office development along Warrenville Road and extends north across the East-West Tollway to serve the Morton Arboretum. Major office tenants located within this service area are R. R. Donnelley Company and ABS/Combustion Engineering. The length of this extension is 1.9 mi.

The second primary extension crosses the East-West Tollway and serves primarily office and multifamily developments to the west along Warrenville Road. This route serves the Arboretum Villages Apartments, the Westwood of Lisle development, the General Accident Insurance Company building, and the Corporate Lakes development, whose tenants include Pansophic, Van Den Bergh Foods, and AT&T. This

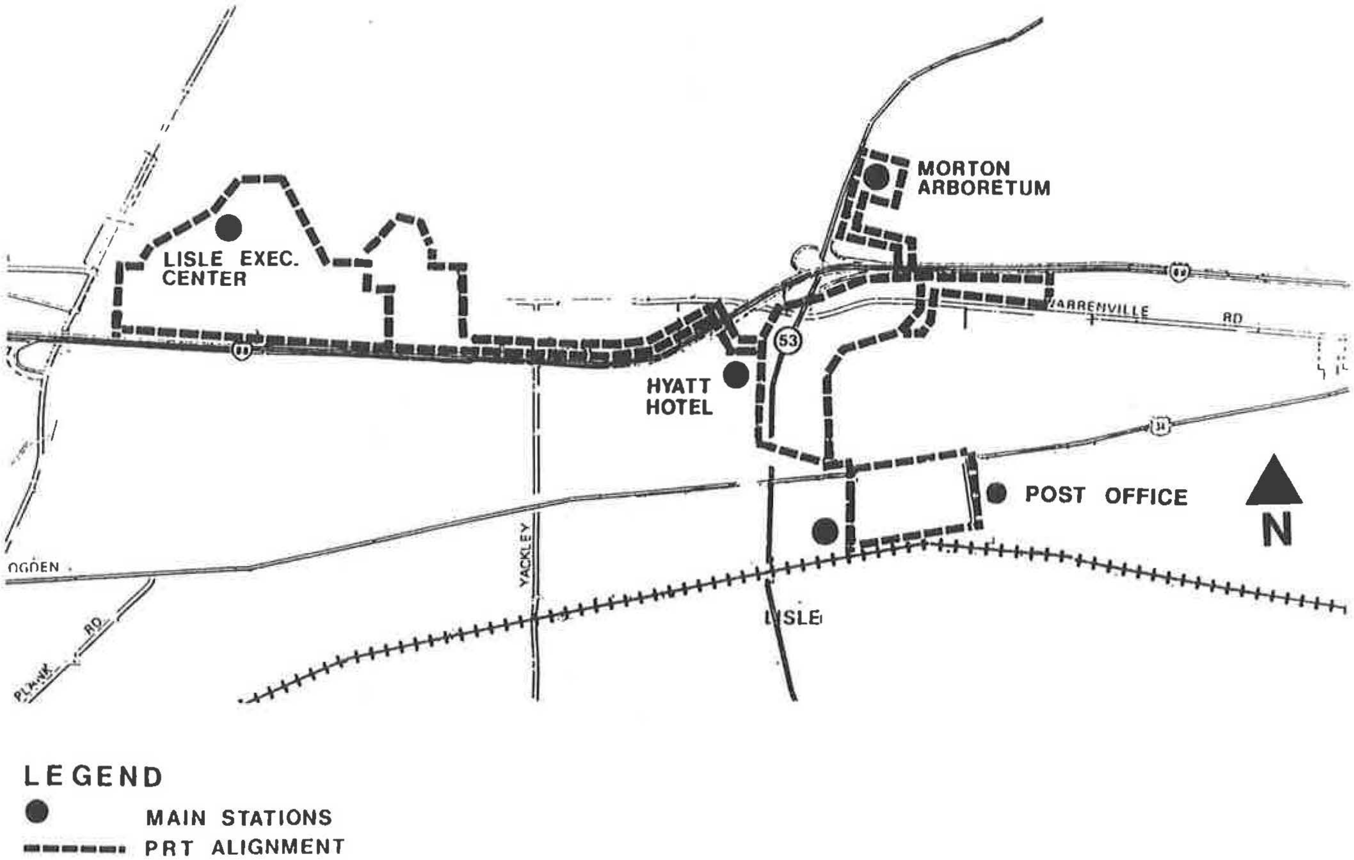


FIGURE 2 Proposed site plan for Lisle.

extension is 2.9 mi long and potentially serves four to seven stations.

Among the other possible system extensions, Lisle has proposed extending the system into Naperville along the Warrenville Road/I-88 corridor and into a light industrial area south of the East-West Tollway that includes a Federal Express distribution center.

Rosemont PRT Site

Rosemont proposes a core PRT system of approximately 2.2 mi, extending to the north and south of the Northwest Tollway and I-190 O'Hare extension along River Road. It is composed of a one-way, figure-8 system that links a concentration of uses in the heart of the village, the Rosemont O'Hare Expo Center, and the Pace/CTA station stop and parking lot at River Road. Hotels located in the initial PRT service area are the Hotel Sofitel, the Hyatt Regency O'Hare, Marriot Suites, Westin Hotel, and Radisson Suites Hotel. The site plan includes elevated and grade-level walkways to link PRT stations with surrounding buildings and to link buildings together. All seven PRT stations proposed for this initial site are standardized, three-level, free-standing structures.

Rosemont proposes three alternative expansions of approximately 2 mi each. The first alternative, known as the West Expansion, consists of a 1.75-mi round-trip loop extending into O'Hare Airport. PRT would connect with the O'Hare Peoplemover system. The Peoplemover system is presently under construction and will link remote parking with the new International Terminal and all domestic terminals.

The second and third alternatives are known as the North Expansion. The first phase of the North Expansion consists of a 2.04-mi round-trip loop extending to Higgins and Devon to the northwest of the initial system. The second phase of this expansion consists of a 2.65-mi round-trip loop extending north to the Rosemont Horizon.

The first phase of the North Expansion would serve primarily Des Plaines and Rosemont office developments along Devon Avenue and Higgins Road. Some of these developments include the O'Hare Office Center, a Xerox office/warehouse facility, the Orchard Point Office Center, and the Executive Estates condominiums. The second phase of the North Expansion would serve development primarily around the Rosemont Horizon. Using right-of-way along the Wisconsin Central Railroad and along Higgins Road, this expansion would serve Des Plaines single-family residents, the Rosemont Horizon, O'Hare Corporate Towers, O'Hare International Office Center, and various hotels.

Schaumburg PRT Site

Schaumburg proposes a 2.15-mi PRT demonstration system serving a development centered around the 2.3 million ft^2 Woodfield Shopping Center. The system serves the west (Nordstrom and Lord and Taylor) and the South (Sears) side of Woodfield. To the north and west of Woodfield, the pro-

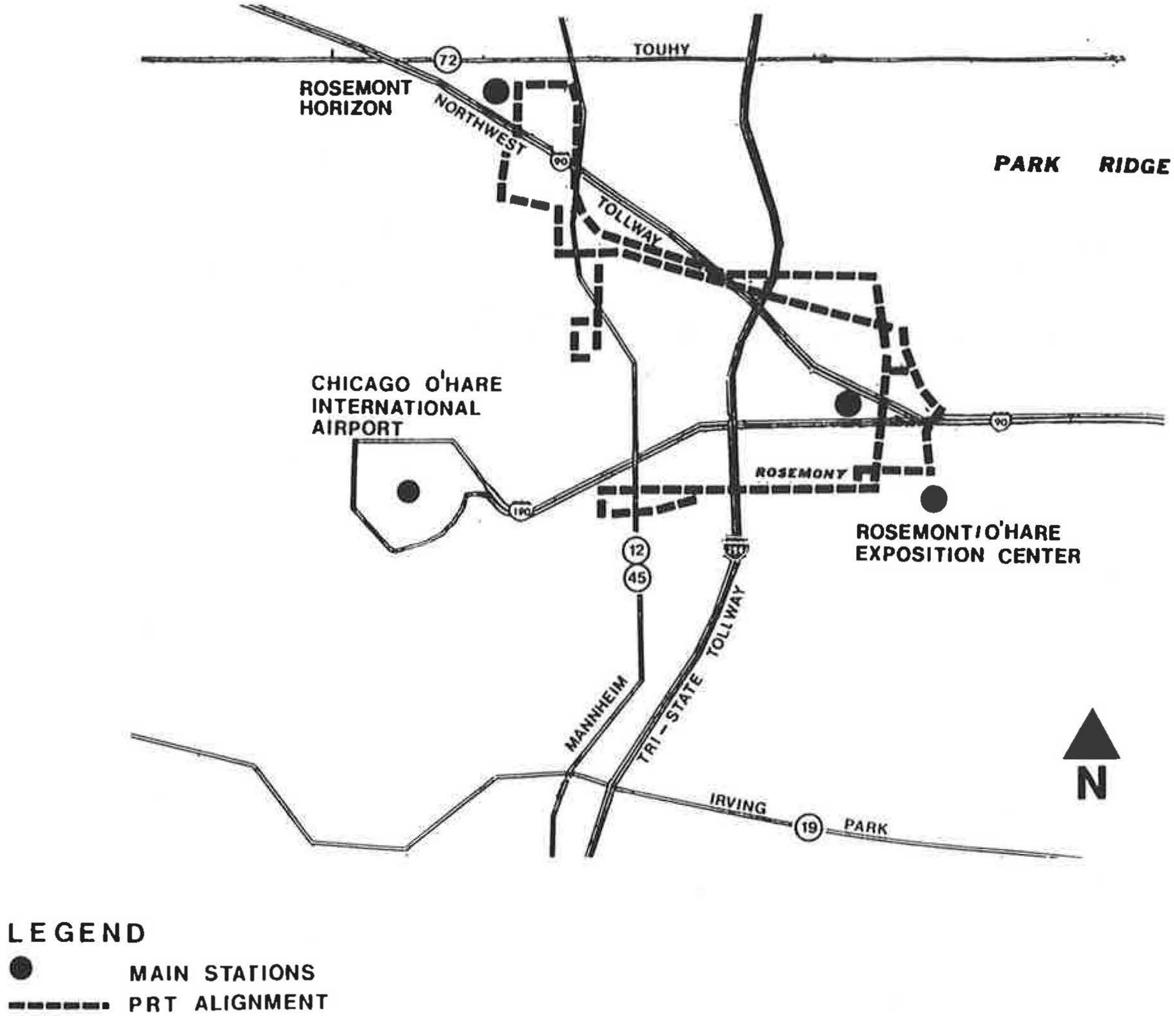


FIGURE 3 Proposed site plan for Rosemont.

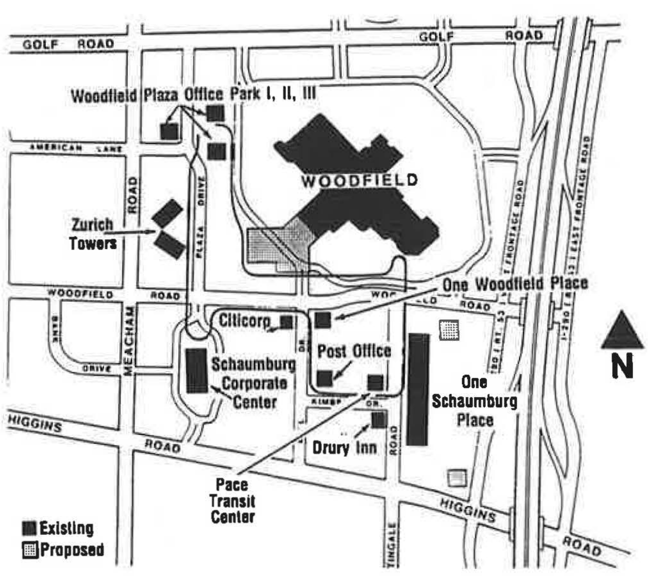


FIGURE 4 Proposed site plan for Schaumburg.

posed system passes the Woodfield Lake Plaza office triangle, Zurich Towers, and Schaumburg Corporate Center. From here, the route turns east linking two more office towers with a proposed Pace Transit Center and a new retail center called One Schaumburg Place. There are eight stations proposed for this initial system.

Schaumburg proposes two expansions, each about 2 mi in length. One expansion travels south along Martingale Road; the other expansion travels through Unocal property to the north. The Martingale PRT extension begins at the Pace Transit Center located at the demonstration route's southeastern terminus. Traveling south on Martingale Road, the route passes three hotels, several restaurants, and 2 million ft^2 of office space. Several hundred residents also live within a short walking distance of this expanded route.

The Unocal property expansion would circulate through 235 acres of mostly undeveloped land owned by Unocal Corporation. This undeveloped land offers the opportunity to integrate PRT stations directly into the design and construction of new office complexes. A Hyatt hotel and 0.5 million ft^2 of office space presently exist on this property, and

Schaumburg has approved 3.6 million ft^2 of additional office development plus retail for this area.

Schaumburg also proposes a future PRT network that would link Schaumburg with Hoffman Estates and Elk Grove Village. The network would serve the nation's largest industrial park in Elk Grove Village and the new Ameritech and Sears headquarters development in Hoffman Estates. Both Hoffman Estates and Elk Grove Village have endorsed Schaumburg's proposal as the logical first leg of the network.

PRT Applications in Northeastern Illinois

Collectively, the community site plans address one of four possible types of applications:

1. *City-to-suburb commute.* Suburban travel demands tend to be too dispersed to handle them efficiently with normal bus service. Pace presently meets some trains at some Metra stations to take Metra passengers to their final suburban destinations, but usually this service is limited. PRT is proposed to connect directly with Metra train service in two of the four site plans. Metra would serve the longer "reverse" portion of a journey in the morning, and PRT would finish the trip. PRT could offer a distinct advantage over Pace service by providing all-day, on-demand, direct service to a variety of suburban locations. Additional Metra service would make this city-to-suburb service even more attractive. Two sites include light industrial development that currently attracts workers living in Chicago.

2. *Suburb-to-suburb commute.* All the proposing communities propose deploying PRT to serve this type of trip. Every proposed site has at least five Pace routes that would connect with PRT and usually begin in some other suburban community. Similar to the reverse commute, PRT would serve the final leg of a longer regional trip. But in this case, Pace instead of Metra would serve as the primary carrier. As an example, a husband and wife could take a bus to a Metra station. One spouse travels downtown to work, and the other takes PRT to a suburban work location. Alternatively, the same couple might drive their car to a Metra parking lot and complete their respective journeys. The husband might return early from work using PRT, travel home to complete household chores, and return to the train station later that evening to pick up his wife.

3. *Intrasite circulation.* All the proposing communities also propose using PRT to circulate and distribute passengers within their own community as well. Typical journeys include work to lunch and back; work to health club and back; work to shopping either during the lunch hour or after work; train station to automobile dealership; hotel to office and back; remote parking facility to Metra station; remote parking facility to regional arboretum; hotel to convention center; or workplace to workplace for business meetings. The communities believe PRT may serve the kinds of trips that currently are taken by private automobile, rental car, or hotel limousine or are not taken at all because of congestion or the logistics of automobile travel.

4. *Goods movement.* At least one site has a post office and Federal Express distribution center close to the proposed site alignment. With a special station designed for these and other similar facilities, PRT could be used to distribute and collect letters, packages, and other business parcels to and from surrounding office developments. PRT would not be subject to the same surface congestion as other truck delivery services and could open up new markets for message and catering services that typically offer over-the-road delivery services during the off-peak hours.

Ultimately, serving these kinds of trips are only a means to a larger goal—increasing trip choice, increasing regional mobility, spurring new, more efficient development, and increasing the region's prosperity and productivity.

CONCLUSIONS

Innovative technologies sometimes require innovative methods for their development and implementation. With a clear-cut need for improved transit technologies to handle the growing and increasingly dispersed suburban travel demands, and in the absence of major private investment and well-defined markets, PRT research and development required such an approach. This paper has summarized the RTA decisions and institutional process that have shaped RTA's PRT Project.

Conducting research and development, and developing a new mode of public transportation, is a risky enterprise. There are no guaranteed payoffs. And by no means is it clear whether RTA will move beyond the initial PRT system design phase. There are technical, institutional, and financial hurdles still to be overcome before any further phases can begin. But the process of designing a research and development effort that attempts to extract a new technology from the private sector while minimizing the public exposure may be worth the risk. After all, RTA thinks that if it does not try, what is at risk is the economic future of Northeastern Illinois.

REFERENCES

1. B. Kamin and D. Ibata. Suburbs Creep Toward Gridlock. *Chicago Tribune*, Feb. 18, 1990.
2. G. Franzen. *Opening Remarks at PRT News Conference.* Regional Transportation Authority, Chicago, Ill., April 24, 1990.
3. Illinois State Legislature. *Regional Transportation Authority Act.* Springfield, Ill. Revised Jan. 1990.
4. Regional Transportational Authority. *Request for PRT Site Proposals.* Chicago, Ill., Dec. 1990.

Publication of this paper sponsored by Committee on New Transportation Systems and Technology.