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Contents

Foreword

Most of the papers in this Record were presented at the January 1991 Annual Meeting of the Transportation Research Board. They provide a good cross section, but certainly not a complete picture, of current research in public transportation. The Record is divided into three parts: Rail Planning and Operations (Part I), Bus Planning and Operations (Part II), and New Technology (Part III).

The six papers in Part I report on studies conducted on management, planning, and operation issues in rail transit. Turnbull documents the results of a four-city survey. Its purpose was to obtain information about and perceptions of what a rail system has done for the quality of life and mobility of a metropolitan area. Each of the selected cities has had a new rail system placed into service in the last few years. Bruun and Salpeas discuss the development and application of a PC-driven program that accurately simulates train operations, plots bidirectional string charts, and allows the sensitivity testing of various operating parameters.

Questions of the effect of the size of the order on purchase prices of railcars are examined by Klein. The analysis indicates that most economies are realized when the order is between 60 and 90 cars. The following two papers discuss topics related to commuter rail operations. Hooson describes the feeder bus program serving the San Francisco Peninsula CalTrain commuter stations, and Gorys et al. describe the 1989 survey of the Government of Ontario commuter rail system (GO Rail). This successful transit system had a 40 percent increase in patronage in a 3-year period. Rotter and McKnight, in the last paper in Part I, provide an overview and evaluation of training programs in rail transit.

The first two papers in Part II, by Welch et al. and Chang and Schonfeld, report on studies that evaluate the effects of bus service that deviates from the traditional fixed-route operation. Levinson et al. describe a study undertaken to determine the limit of acceptable express bus service in Manhattan. Whereas certain areas of the central business district had little space for additional express buses, the analysis indicated that limits on the number of express buses do not appear practical at present, because bus volumes entering Manhattan have been declining.

Strathman and Hopper discuss automatic passenger counter issues relating to data validation, sampling methodology, and system-level ridership determination from sample data. The study was conducted at the Tri-County Metropolitan District of Oregon. Adelman and Danker describe how Virginia evaluates applicants for grants under the Urban Mass Transportation Act Section 16(b)(2) program. The described procedures should be useful to administering agencies of other states. Maze et al. discuss drug-testing requirements for safety-sensitive workers. The new requirements place a severe administrative burden on small urban and rural transit agencies. Maggio et al. provide an overview of the physical and handling properties, health hazards, and supply issues related to the most widely used alternative fuels. The last two papers in Part II report on studies related to intermodal transfer facilities. Rutherford et al. deal with park-and-ride lots, and McConnell and Gray discuss the Transbay Transit Terminal in San Francisco.

The four papers in Part III cover people mover systems at high-activity centers. The papers by Sproule, Smith, and Leder discuss applications of automated systems currently in use at airport terminals and projects under development. Dutta et al. review the maintenance experience of the Detroit Downtown People Mover, which has been in operation since 1987. They discuss the 1989 data and determine the relationship among various entities of the maintenance system.

Image of Rail Transit

KATHERINE F. TURNBULL

Many aspects of rail transit systems are often classified as intangible—that is, they are perceived as beneficial but are difficult or impossible to quantify. Included in this category are the image that the rail system projects; the system's effect on the city's image, marketing and promotional activities, and land use and development; and the perception of what the rail system has done for the quality of life and mobility of an area. To obtain a better understanding of the impacts that rail transit systems have had on these aspects, the Texas Transportation Institute, under contract to the Metropolitan Transit Authority of Harris County (Houston Metro), conducted interviews with representatives of agencies and organizations in four cities that recently implemented rail transit systems: Atlanta, Miami, Portland, and San Diego. Similar interviews were conducted in Houston, allowing a comparison of responses in Houston with those from the other cities. The results, which provide a qualitative, rather than quantitative, assessment of some of the less tangible aspects of rail transit systems, should benefit metropolitan areas where rail transit systems are being considered and practitioners attempting to better understand the rail transit decision-making process.

Many aspects of rail transit systems have positive effects on the communities in which the systems are located but are difficult or impossible to quantify. Intangible aspects include such things as the system's effect on the city's image, marketing and promotional activities, and land use and development, and the perception of what the system has done for the quality of life and mobility of an area. Many of these elements have been identified as important aspects of rail systems and have been cited as considerations in the decision-making process used in some cities (*1,2*).

The research presented here was conducted by the Texas Transportation Institute (TTI), a part of the Texas A&M University System, under contract to the Metropolitan Transit Authority of Harris County (Metro). Metro requested that TTI examine the less tangible effects of rail transit systems. The results provide information on the impact of these attributes and enhance the understanding of the role these aspects may play in the rail transit decision-making process. The results should benefit metropolitan areas in which rail transit systems are being considered. The analysis provides a qualitative, rather than quantitative, assessment of many of the less tangible aspects of rail transit systems. However, given the importance of these attributes, the analysis provides valuable insight into the less tangible aspects of rail transit. Additional research is suggested to more fully comprehend these impacts.

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METHODOLOGY

The process used in this assessment focused on conducting structured interviews with individuals from similar agencies and organizations in four cities that have recently implemented rail transit systems: Atlanta, Miami, Portland, and San Diego. In addition, interviews were conducted in Houston to allow a comparison of the responses in a city considering a rail system. In each city, interviews were held with representatives from some combination of the following organizations and agencies: transit authority, metropolitan planning organization (MPO), state department of transportation, downtown development group, chamber of commerce, visitors and convention bureau, private developer or development organization, and the city. Table 1 presents a summary of the agencies and organizations included in the interview process in each city.

In every case, representatives from the transit authority, MPO, and state department of transportation were interviewed. Representatives from other appropriate groups were interviewed depending on the organizational structure in the area. A total of 24 interviews were conducted in the four rail cities, with 5 to 8 interviews in each city. Seventeen interviews were conducted in Houston.

Additional research activities were completed to support the interviews. Promotional and marketing materials obtained from many organizations in the four cities were reviewed to assess how prominently the rail system was featured. Relevant reports and documents, such as those on economic development activities, traffic impacts, and public opinion polls, were obtained from some areas and reviewed, along with newspaper and journal articles identifying public and political reaction to the projects. Finally, a limited number of telephone interviews were conducted with representatives of firms specializing in helping businesses to make locational decisions. The purpose of these interviews was to identify the impact that rail systems may have on the business location decision-making process.

The approach used in this analysis is not without drawbacks. The interviewees provided relatively objective responses to questions. Most were open about discussing both the positive and negative impacts of the rail systems. In addition, a number of people identified situations in which anticipated benefits, such as new development, had not occurred. However, despite the overall objectivity of the interviews, some statements can be viewed as overly positive or public-relations oriented. This is not surprising given the significant investment that the rail systems represent, and an effort has been made to examine other relevant information and to put these statements in the proper context.

TABLE 1 AGENCIES AND ORGANIZATIONS INCLUDED IN THE INTERVIEW PROCESS

	Atlanta	Miami	Portland	San Diego	Houston
Transit Authority	X	X	X	X	X
Metropolitan Planning Organization	X	X	X	X	X
State Department of Transportation					
City	X	X	X		X
Downtown Development Group	X	X	X	X	X
Chamber of Commerce/Visitors & Convention Bureau	X		X		X
Private Developer or Development Organization	X		X	X	X

A structured process was used in each interview. Topics covered in the interviews included assessments of the rail transit system on the basis of

- The image it projects;
- The image of the city;
- The quality of life;
- Access to employment, shopping, education, and entertainment;
- Service to low-income areas and increased access to employment opportunities;
- Use in marketing and promotional activities of the city;
- Influence in attracting new businesses to locate in the city or in business relocation decisions;
- Energy, air quality, and environmental improvements; and
- Urban congestion levels.

Other topics covered in the interview included general reactions concerning

- Perception of bus and rail transit, including that of the general public;
- Factors that should be considered in the rail transit decision-making process;
- Public reaction to the rail system; and
- Local policies or programs supporting the use of transit or land use and development changes, or both.

Whereas the impact of rail transit on economic development and land use was analyzed separately (*3*), interviewees were asked for their perception of the impact of rail in these areas. In addition, the general approach used in the four cities for coordinating and promoting development in conjunction with the rail system was examined.

RESULTS

Quality of Life, Attractiveness, and Accessibility

In all four cities, the interviewees indicated that the rail systems have had a positive impact on the quality of life, attractiveness, and accessibility of the cities. The impacts most often mentioned were maintaining and enhancing the vitality of the downtown area and providing access to other major activity centers, such as suburban shopping centers, educational institutions, sports complexes, and cultural centers. Many individuals also noted that the systems provided high levels of service to both transit-dependent groups and choice riders.

The downtown was identified as the area receiving the major benefits from the rail systems. This was voiced most strongly in Portland and Atlanta. Interviewees in Portland noted the longer weekend shopping hours and increased sales of downtown businesses as examples of this impact. The Portland experience has been documented in other reports and surveys of downtown businesses (*4*). A number of interviewees noted that rapid transit has made the downtown area of Atlanta a more attractive place to live and work and that it would be difficult to serve the downtown work force without it. The improvement was ascribed not only to the attributes of the rail system, but also to its resulting in the removal of buses from downtown streets.

Positive impacts on other areas of the city and facilities served by the rail systems were also noted. For example, in Atlanta, Miami, and San Diego, the rail lines serve major educational institutions. Provision of greatly improved access to these junior colleges, colleges, and universities was noted as an important feature of the systems. Service to cultural and sporting activities, such as Metropolitan Atlanta Rapid Transit Authority (MARTA) service to the Arts Center and Omni Complex, was cited as a further example of the positive impact of the systems on mobility and accessibility.

In Atlanta, Miami, and Portland, major suburban shopping centers are accessible by the rail systems. Some interviewees noted that, although initially the managements of these facilities had not always been enthusiastic about the rail connections, citing potential increases in vandalism, the experience in most areas had been positive. Interviewees in all four systems emphasized the role the systems played in increasing accessibility and mobility for low-income and minority groups.

Image

Representatives of Atlanta, Portland, and San Diego all believed that the rail systems provided the image of a progressive, forward-looking city. They indicated that the rail systems have projected this positive image from the start. A number of the people interviewed in Miami admitted that MetroRail started with a negative image because of low ridership levels and high capital costs. However, they believed that the image of the system was now much better and contributed positively to the image of Miami. A review of newspaper articles from the time of the opening of the Miami system supports the belief of an initial negative reaction (*5*).

Interviewees in all four cities indicated that the rail systems were thought of as integral parts of the cities' images. Rail was believed to enhance the image they wanted to project—that of progressive, forward-looking, high-technology cities. Many people, especially representatives of cities whose neighbors do not have rail systems, noted that the rail systems set them apart from other cities. Thus, Portland noted that Seattle does not have a rail system, San Diego mentioned that the

Trolley sets it apart from Los Angeles and Orange County, and Miami noted that Orlando does not have a rail line.

Whereas the image aspect of rail was mentioned by everyone, it was noted most strongly by interviewees involved in marketing and promotional activities. These representatives stressed the important role image plays in selling, marketing, and promoting a city. The rail systems were believed to provide an additional tool the cities could use to compete with other areas and to further enhance the progressive and "world class" image the cities wanted to project. A number of interviewees indicated that the rail systems had provided an important psychological boost for the city. They linked this to the pride many residents expressed about the systems. This was noted most strongly in Portland and San Diego.

Perception of Rail Versus Bus

All interviewees indicated that they believed rail transit to be perceived differently from buses by the public and policy makers. Terms used to characterize the superior perception of rail included the following: a fixed facility that people know will be there, more dependable and reliable, more comfortable and attractive, faster, sleeker, and a higher-class service. These characteristics were deemed to be important to the image projected by the system and the city. An interviewee in Miami indicated that when focus groups in a test marketing program were shown videos with mostly buses and only a few rail pictures, the thing people remembered most was the rail vehicles.

Telephone interviews conducted with representatives of business location firms supported this perception of rail, although not quite as strongly. Interviewees indicated that most businesses view the availability of rail transit service more positively than bus because it is a fixed facility and because of its speed, attractiveness, and visibility. As one representative indicated, "Rail sticks out." However, most indicated that transit service in general, whether bus or rail, is not usually one of the major factors in the business location decision-making process.

Marketing and Promotional Activities

All interviewees in the four cities indicated that the rail systems are used in the cities' marketing and promotional efforts. Most noted that the rail system plays an important, but supporting, role in these efforts and is an additional tool the city can use in competing with other cities. The rail system is shown as one element of the total transportation system and is highlighted to promote the accessibility and ease of travel within the area.

A review of marketing and promotional materials from the different organizations within each city reinforces these statements. Pictures of the rail systems are used in many publications, often in prominent locations, and information on the systems is provided in the text in a supporting fashion. Thus, the appearance of the systems is important in the promotional activities of the areas. Pictures of the system are usually more prominently displayed than actual information. For example, the Atlanta Chamber of Commerce publication on transportation in metropolitan Atlanta features a picture of a MARTA vehicle on the cover, and a note in the introduction indicates that MARTA service was recently extended to the airport. However, actual information on MARTA is contained on page 15, following information on Hartsfield International Airport, cities with scheduled air service to Atlanta, airlines serving Atlanta, general aviation, railroads, highways, motor freight, and freight forwarders (*6*).

The interviews indicated that the rail systems are viewed as especially important in marketing efforts oriented toward attracting visitors, tourists, and conventions. For example, a number of people in Atlanta suggested that MARTA had helped to attract the 1988 Democratic National Convention to the city. It was also noted that MARTA was being used heavily in Atlanta's bid to host the Olympics.

Public Reaction and Perception

In general, the rail systems were thought to be well received by the general public, although many interviewees prefaced their response with "it depends on whom you talk to." Overall, most people indicated that the systems were perceived positively and believed to be of benefit to the area. It was suggested that they were viewed most positively by riders and the downtown business community. People who do not use the system and residents and businesses in areas that are not served may be less supportive.

In Miami, several interviewees noted that some of the problems encountered when the system first opened, such as lack of coordination with and low levels of feeder bus service, contributed to some of the initial negative feelings toward MetroRail. The initiation of the rail service and restructuring of the bus system were described by some as "traumatic" and "chaotic." However, most indicated that support for the system has grown as service improvements have been made.

In Portland and San Diego, the interviewees indicated that the rail systems enjoy widespread support from both users and nonusers. Representatives in Portland cited recent telephone polls and business surveys to gauge this support. In San Diego, the 1987 election, in which voters approved an additional ½ percent sales tax to be used for transportation improvements, including one-third of the total for rail expansions, was cited as the best measure of the public's support for the system.

Congestion, Energy, and Air Quality

Most interviewees indicated that the rail systems have probably had only a minor impact on congestion levels, energy, and air quality, although most believed that these had been important considerations during the decision-making process. Respondents in all areas indicated that the rail systems had added needed capacity to the corridors in which they are located and had reduced bus congestion on downtown streets. In addition, interviewees in some areas indicated that the rail systems had helped with specific "hot spot" air quality concerns, but none could site specific studies. The best before-and-after evaluation of some of these factors was conducted by the Atlanta Regional Commission (ARC) during the initial phases of MARTA development. However, the results of the traffic monitoring study conducted by ARC were inconclusive because of a lack of discernible trends and the potential impacts of external factors (*7*).

Development and Land Use Impacts

The questions relating to development and land use impacts focused on the approach used in the different cities to promote and coordinate these activities and the general perceptions of the impact that the rail systems have had on land use and development. A more detailed examination of the impact of rail transit on economic development and land use was conducted separately (*3*).

The impact of the rail systems on development and land use patterns was perceived differently in the four cities. In general, all interviewees believed that the rail systems have had a positive impact on development, but the level of this impact was viewed differently. Representatives in Atlanta and Portland expressed stronger support for the impact that the rail systems have had on development than those in Miami and San Diego. This is in part due to the approach used to promote and influence development in conjunction with the rail systems. Atlanta and Portland have taken a planned approach to focusing future growth around the rail system and encouraging the use of transit through supporting policies, which include rezonings, density and parking trade-offs, parking policies and pricing, and other incentives. On the other hand, Miami and San Diego have taken a less active approach to encouraging and promoting development. The lower level of development activities associated with the rail systems in these two areas may reflect this approach.

The interviews and literature review indicate that examples of new development adjacent to the rail systems exist in all four cities. In all cases, representatives noted that the impact has been primarily on regional locational decisions rather than attracting new business from outside the region. This contention corresponds to the conclusions reached in the independent analysis (*3*) and the interviews conducted with representatives of business location firms.

The important role of supporting and complementary policies was also noted. All interviewees noted that other policies, such as those relating to parking requirements, zoning, land use, and density can be used to encourage development at certain locations. In addition, several interviewees noted that the systems are still relatively new and that the full development impacts have not yet been realized.

Representatives in all four cities indicated that the rail system was not the major reason for the location of the new developments, but that it was an important element in the decision-making process. Many also indicated that the rail system helps make existing development function better. The ability of rail transit to deliver large volumes of people in a short time was identified as a major feature that attracted development.

Many respondents were open about discussing areas where the rail system had not yet influenced new development or redevelopment. For example, many people in Atlanta expressed disappointment that MARTA had not yet been able to attract new development around some stations. It was noted that the presence of MARTA alone is not enough to overcome historical development patterns or market forces. Even in these cases, however, interviewees in all four cities indicated that development potential was still present.

Reasons To Build Rail

The last set of questions focused on identifying the most important reasons why an area should consider a rail transit system. The factor mentioned most frequently was the need to move large numbers of people. Thus, ridership was most often cited as the key criterion. The next-most-often-cited elements were the potential for long-term savings in transit operating costs, the potential for encouraging development, enhancing the image of the city, and other factors. Most respondents indicated that the transportation function of the system was most important and that other factors, such as the potential to influence development and enhance the image of the city, should be considered secondary benefits.

SUGGESTIONS FOR ADDITIONAL RESEARCH

The information presented in this paper provides an initial assessment of many of the less tangible qualities of rail transit systems. However, additional research is needed to obtain a deeper understanding of the impact and importance of these attributes. To accomplish this, a number of areas are suggested for further study.

The first consideration is to include more cities in the analysis. Conducting interviews in other cities would expand and enhance this initial assessment. A more detailed examination of local studies and data should be included. Budget and schedule limited the number of cities and interviews in this study.

Consideration should also be given to determining whether there is a difference in the perceptions of different types of rail systems. No attempt was made in this initial effort to distinguish between the impacts of light rail, heavy rail, and automated guideway systems. In addition, a further comparison of perceptions associated with automobiles, buses, high-occupancy-vehicle facilities, rail, and advanced technologies would be of benefit.

Another area for analysis is a more detailed examination of the supporting policies and programs that have been used to promote development in conjunction with rail transit systems and to encourage ridership. It appears that these policies and incentives are important in influencing development and land use adjacent to the rail line. Such a study would be of benefit in areas where enhancement of current projects or implementation of new systems is being considered.

CONCLUSION

The results of this analysis provide a qualitative assessment of some of the less tangible aspects of rail transit systems. These attributes have often been noted as important factors influencing the rail transit decision-making process. The information presented in this paper should enhance the understanding of many of these aspects of rail transit. The results should be useful in metropolitan areas where rail transit systems are being considered and to practitioners attempting to better understand the rail transit decision-making process.

For example, the results were used as one element of the ongoing consideration of rail transit in Houston. As noted, a series of interviews with representatives from similar agencies and organizations was conducted in Houston in 1989. The results of these interviews were compared with those from the four cities described in this paper. This allowed decision makers to compare the perceptions of individuals in Houston with those of the representatives of the four cities, which was beneficial in the discussion of the importance and role that these less tangible aspects of rail should play in the decision-making process. Similar comparisons may be useful in other areas considering rail transit systems.

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Train Operations Computer Simulation Case Study: Single-Tracking Operations for Philadelphia's Market-Frankford Subway Elevated Rail Rapid Transit Line

ERIC BRUUN AND P. TAKIS SALPEAS

The graphical portrayal of train operations using time-distance diagrams has long been used to develop schedules and for other analyses. The availability, however, of relatively simple, practical, user-friendly computerized tools to do the related calculations and plots is limited. The development and application of a package of PC-driven programs that accurately simulates train operations, plots bidirectional operations charts and schedules, and allows sensitivity testing of various operating parameters are discussed. The package was tested using data derived from the operations of Philadelphia's Market-Frankford subway elevated rail rapid transit line. It then successfully generated graphical schedule (string-chart) diagrams for this two-track line under a series of operating assumptions. Of special interest was the testing of the present schedule while a section of track 599 m (1,964 ft) long between two stations was taken out of service. Such a package can be easily developed and used for a variety of sensitivity analyses, graphical scheduling, and other operational tests.

Philadelphia's Market-Frankford subway elevated (MFSE) rail rapid transit line spans 21.24 km (13.2 mi) and serves Center City through seven subway stations. This two-track line with 9 stations on the western elevated portion (Market El) and 12 stations on the eastern elevated portion (Frankford El) carries nearly 200,000 passengers per day. Nearly one of every four Center City jobs is reached via this line. Its reliability and high-performance service are instrumental in the city's daily functioning. The Southeastern Pennsylvania Transportation Authority (SEPTA) provides maximum service of up to 35 trains eastbound during the 2-hr p.m. peak period.

The eastern elevated portion is undergoing reconstruction. To minimize passenger disruption, SEPTA solicited competitive bids for the reconstruction of an elevated section on the basis of a one-track-at-a-time construction method. Bidirectional passenger service was to be continued on the basis of a single-tracking operations plan.

The PC-based simulation program described in this paper was an important tool in testing whether a single-tracking schedule could be developed to operate the number of trains that is normal when both tracks are in service. The formal scheduling for MFSE operations, however, was beyond the scope of this work. This schedule may be influenced by additional factors that can best be assessed by SEPTA's scheduling and operations departments.

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BACKGROUND

The MFSE line serves Philadelphia with 2 multimodal terminals and 26 intermediate stations. One-way travel time is approximately 40 min. The average station spacing is 816 m (2,677 ft). Each station is designated as A, B, or AB. During peak periods, A trains stop at A and AB stations and B trains stop at B and AB stations in a "skip-stop" operation. Operation is local during all other periods. Figure 1 shows a schematic of the 1,964-ft single-tracking section.

Figure 2 shows the frequency of service provided during the 2-hr peak period (3:30–5:30 p.m.) by 15-min intervals. The figure indicates that up to 70 trains have been operated during this period. In particular, between 4:45 and 5:00 p.m., seven trains were operated in each direction. (The current schedule runs slightly fewer trains to adjust for lower demand.) This period is the most critical and is the motivation and test case for the simulation software described here.

SIMULATION METHODOLOGY

The simulation process is based on a set of motion equations taken from a prominent textbook (*1*).

Equations of Motion

The rapid transit line is modeled as a series of interstation spacings, each station being numbered sequentially. Associated with each station number is the station type (A, B, or AB). Trains stop at all stations in nonpeak periods. Each station (i) has a dwell time (t_{si}). Given n stations there must be $n - 1$ interstation spacings (S_i), each with an average cruising speed (v_i).

Travel time on any interstation spacing is composed of the times required for accelerating to cruising speed, running at cruising speed, decelerating into the station, and the station dwell time. The sum of the terms for the incremental deceleration time of entering Station i, dwell time, and incremental

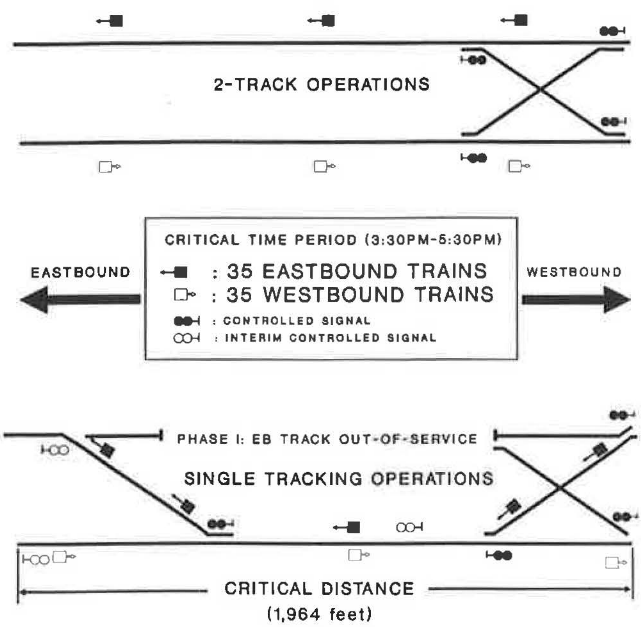

FIGURE 1 Schematic problem definition, two-track versus single-tracking train operations.

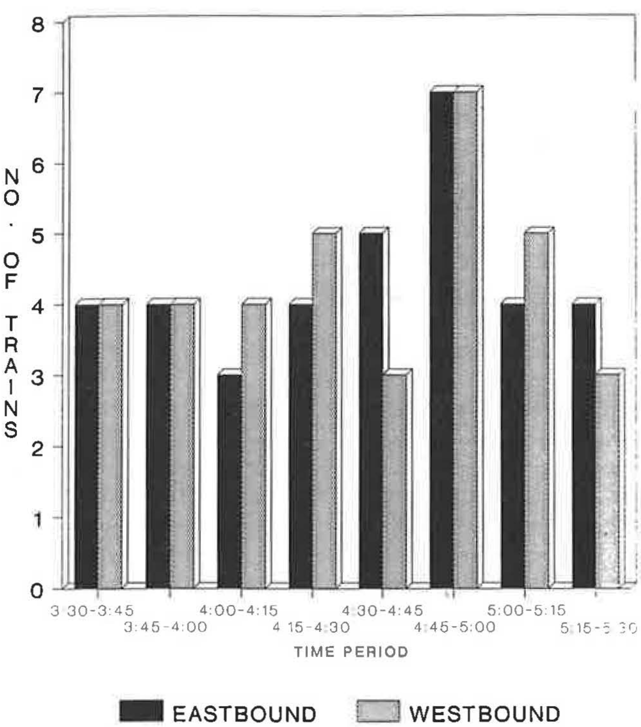

FIGURE 2 Frequency of service profile, 3:30 to 5:30 p.m.

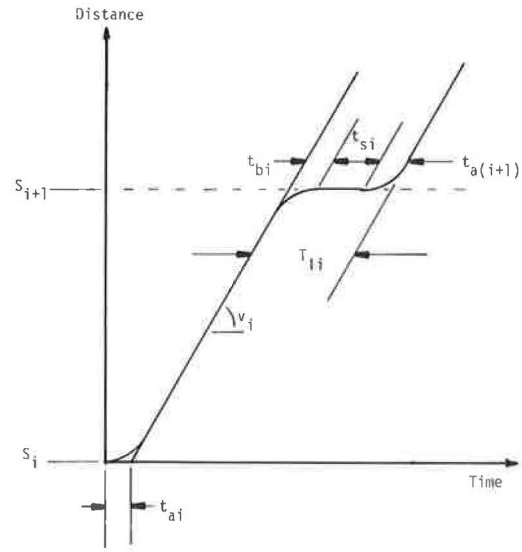

FIGURE 3 Stopping at a station.

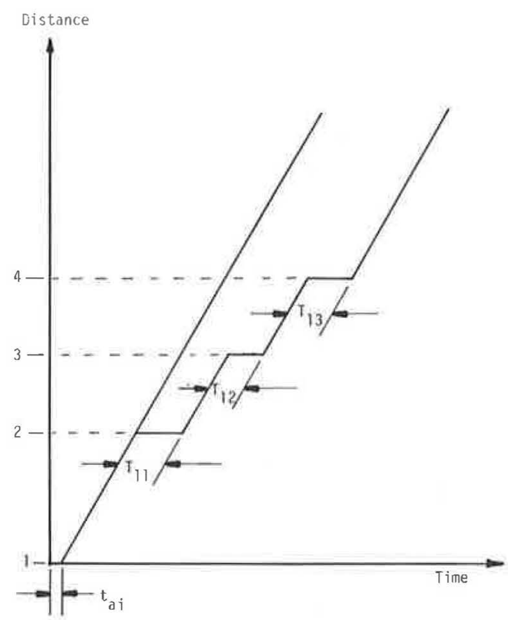

FIGURE 4 Time-lost graphical method.

acceleration time back to cruising speed in the next spacing may be viewed as time lost for stopping, or T_{li}, as shown in Figure 3.

Figure 4 shows a straight-line approximation of time lost for each stop instead of acceleration and deceleration curves. This simplification is convenient for plotting and yet sufficiently accurate for scheduling purposes. Each time-lost line is connected to the next by a straight line of slope equal to the cruising speed between them. If the cruising speed varies among the interstation spacings, the sloped lines representing the cruising speeds will no longer be parallel.

Unless the station spacings are extremely short, a constant acceleration rate ($\bar{a}$) and constant braking rate ($\bar{b}$) can be assumed, generally on the basis of experimental measurements for existing rolling stock and an integrated average for hypothetical rolling stock. (It is not difficult to develop a variable rate $\bar{a}$ or $\bar{b}$ if needed.) Once these values are known, the distance in which the rolling stock accelerates to cruising speed from zero and then immediately decelerates back to zero can be computed. It is not necessarily a constant value for all interstation spacings, because it is a function of the variable v_i as well as $\bar{a}$ and $\bar{b}$. This distance is called the critical distance, S_{ci}, and is given by the formula

$$S_{ci} = \frac{v_i^2}{2}\left(\frac{1}{\bar{a}} + \frac{1}{\bar{b}}\right) \quad (1)$$

The formula to apply for computation of travel time depends on whether the interstation spacing S_i is less than or greater than S_{ci}. If $S_i \leq S_{ci}$, the vehicle never reaches cruising speed before slowing down again. If $S_i > S_{ci}$, the vehicle can cruise for a time before decelerating again. In the first case, the interstation travel time over Spacing i, including dwell time at Station $i + 1$, is

$$T_{S_i} = t_{a_i} + t_{b_i} + t_{S(i+1)}$$

$$= v_i' \left(\frac{1}{\bar{a}} + \frac{1}{\bar{b}}\right) + t_{S(i+1)} \qquad S_i \leq S_{ci} \quad (2)$$

In this situation the speed reached (v_i') is not known beforehand; it is only known that $v_i' < v_i$. Therefore, it is better to express this relation in terms of the known value S_i:

$$T_{S_i} = \sqrt{\frac{2(\bar{a} + \bar{b})S_i}{\bar{a}\bar{b}}} + t_{S(i+1)} \qquad S_i \leq S_{ci} \quad (3)$$

The other case, $S_i > S_{ci}$, has four, not three, components of travel time: acceleration time to v_i, deceleration time from v_i to zero, dwell time at the next station ($t_{s(i+1)}$), and cruising time at the constant speed v_i. The equation is

$$T_{S_i} = v_i\left(\frac{1}{\bar{a}} + \frac{1}{\bar{b}}\right) + t_{S(i+1)} + \frac{S_i - S_{ci}}{v_i} \qquad S_i > S_{ci} \quad (4)$$

The graphical interpretation and plotting become straightforward with these relationships. If $S_i > S_{ci}$, the last term is drawn as a straight line with slope v_i and length required to reach Station $i + 1$ (a vertical distance S_i), with three other components following as a horizontal line of length T_{li}, shown in Figure 3. Thus, T_{li} associated with a stop can be calculated by adding the three time components due to stopping, standing, and starting again:

$$T_{li} = v_i\left(\frac{1}{\bar{b}}\right) + v_{i+1}\left(\frac{1}{\bar{a}}\right) + t_{S(i+1)} \qquad S_i > S_{ci} \quad (5)$$

If $S_i \leq S_{ci}$, the situation is not as clear, because there is no real constant speed component. However, for plotting purposes it suffices to use an approximate straight line. This approximation, shown in Figure 5, is formed by drawing a line between distances S_i and S_{i+1} of time equal to the first term in Equation 3. Again, time lost is drawn as a horizontal line; by inspection of Figure 5, the revised time lost (assuming the following spacing is longer than critical distance) must be

$$T_{li} = t_{a(i+1)} + t_{S(i+1)}$$

$$= v_{i+1}\left(\frac{1}{\bar{a}}\right) + t_{S(i+1)} \qquad S_i \leq S_{ci} \quad (6)$$

A graphical schedule can be built by repeating these calculations for each interstation spacing. Each time-lost moves the plotter coordinates further to the right and each cruising speed moves the pen diagonally to the right until the entire set of interstation spaces has been processed. The first and last spacings are special cases due to either no initial braking or no final acceleration, which slightly complicates the algorithm. There is one further slight complication if two spacings less than critical occur consecutively.

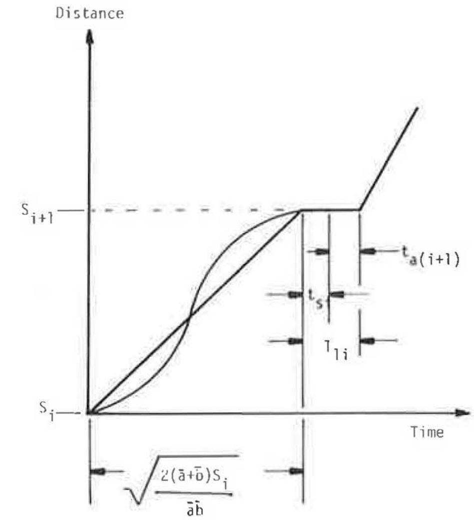

FIGURE 5 Graphical method for distances less than critical.

Under local operation, the calculations consist of simple additions of travel time for each station spacing. However, under skip-stop A operation, preliminary sorting must be done to add distances together where stops are eliminated and to reindex the stations and interstation spacings to reflect the changes. If two spacings that are joined together have different average cruising speeds, the distance-weighted average of the two can be used as an approximate value, v_j, for the new interstation spacing, SA_j. The equations are of the same form as before, but fewer iterations are necessary because there are fewer spacings. The relationships for skip-stop B operation are similar.

To draw a time-distance diagram for one run of one train, the dispatch time from the terminal is required to locate the starting-time coordinate. An entire time-distance chart can be made by giving each dispatch time and consecutively plotting each train scheduled during the analysis time period.

Practical Modeling Issues

A practical model requires provision for simulation of irregularities, including delays at particular points for particular trains. Such delays can easily be modeled as "lumped" penalties at stations by using the relation

$$t_{Si}\,(\text{new}) = t_{Si} + t_{pi} \quad (7)$$

where t_{pi} is an additional amount of time lost to be imposed at Station i. Thus, one is simply changing the effective value of dwell time at Station i as far as the equations are concerned.

A special operating problem that the model must address is single-tracking conflicts. If two lines on the diagram, one from each direction, cross each other within the section of single tracking, there is a conflict. This concept is shown in Figure 6. The time delays required for switching or for signals to clear at crossovers (or both) can be modeled by using the aforementioned penalties, or a dummy station at a point of delay can be added to the model.

A possible useful modification to the equations of motion, not used here, would be to allow coasting on all interstation spacings greater than critical. This would allow analysis of sensitivity of operating time with respect to coasting regimes. The formula is

$$T_{S_i} = \frac{S_i}{v_i} + \frac{v_i}{2}\left(\frac{1}{\bar{a}} + \frac{1}{c}\right) + \left(v_c - \frac{v_c^2}{2v_i}\right)\left(\frac{1}{\bar{b}} - \frac{1}{c}\right) + t_{S(i+1)} \qquad S_i > S_{ci} \tag{8}$$

where c is the coasting deceleration rate and v_c is the minimum acceptable coasting speed. One more component, which would be acceptably represented on the time-distance diagram as a change in slope from cruising speed to a reduced average speed on the coasting portion of the section, would be added to the interstation travel time (see Figure 7).

The scatter observed in real operations, like those of the MFSE line, could be simulated by using a probability distribution function for the average cruising speed and for station standing times. It would then be possible to generate numerous charts to visualize how often trains lose sufficient separation and where a conflict is likely to occur.

Software

The program was implemented primarily in Turbo Pascal using a menu-driven format. The main menu shows eight selections or modules. Module 1 merely terminates the program. Modules 2, 3, and 4 are used to input the descriptions of the line, operating parameters, and setup. Module 5 begins the calculations and displays the initial results. Module 6 can be used to draw individual time-distance diagrams, and Module 7 can be used for scheduling and fleet size computations. Module 8 generates the operations chart and train schedules.

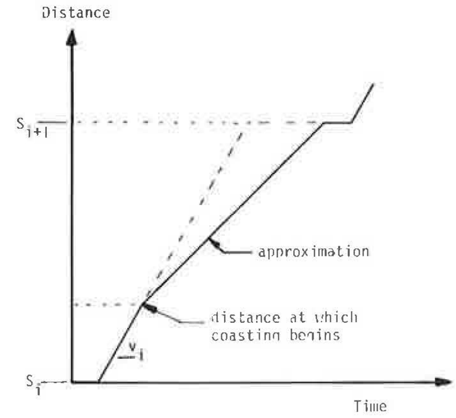

FIGURE 7 Graphical method for coasting between stations.

The program accepts the following input variables:

- Acceleration rate ($\bar{a}$, m/sec²);
- Deceleration rate ($\bar{b}$, m/sec²);
- Average cruising speed (v_i, km/hr), variable between stations;
- Dwell time (t_{si}, sec), variable for each station;
- Station spacing (m) and station type (A, B, or AB);
- Minimum station headway (zonal only) (sec);
- Terminal time percent (XT_o, dimensionless);
- Minimum terminal time (TT_{min}, min);
- Scale factor to optimize use of screen for line drawing;
- Fixed time scale for time-distance plots (min);
- Desired headway (min) (optional); and
- Maximum passenger load (P_{max}), load factor, size of car, and number of cars per train (optional).

The following results are produced:

- Line operating speed (Vo, km/hr);
- Line operating time (To, min);
- Line drawing showing lengths (S_i) and interstation travel time (T_i) for skip-stop A, skip-stop B, and local operation;

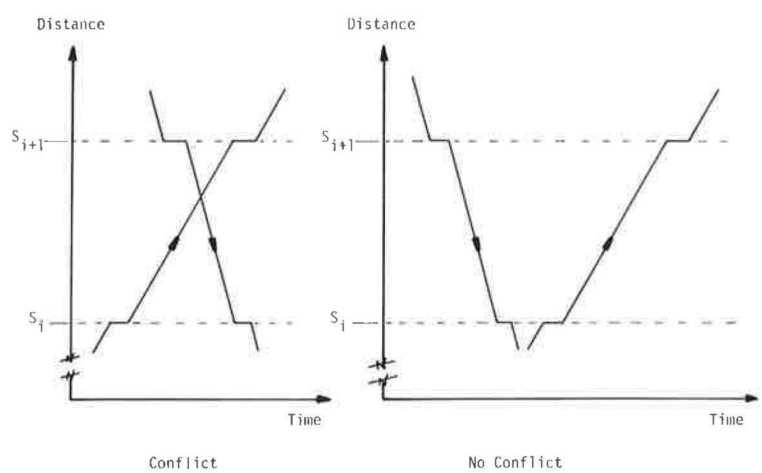

FIGURE 6 Possible conflicts on single-tracking section.

- Operating speed (Vo) and operating time (To) for both zones during zonal operation;
- The minimum zonal headway (hzmin, min);
- Time-distance diagrams for local, skip-stop A, skip-stop B, or any combination overlaid; and
- Time-distance diagram for both zones simultaneously.

The following additional results are available:

- Terminal time based on tt = max $\{XT_o, TT_{min}\}$ (min);
- The adjusted cycle time (T_1) by rounding T/h (min);
- The adjusted terminal time (tt_1, min);
- Number of trains (Ntu) for steady-state operation; and
- The required headway (h, min), if P_{max} and other related parameters are specified.

Each module is briefly described below.

Module 2, Rolling Stock Characteristics, is used to input the acceleration, deceleration, interstation cruising speeds, and station dwell times.

Module 3, Station Spacings and Types, is used to input the distance between stations and the type of station (A, B, or AB). A line schematic with lengths proportional to interstation distances is drawn as the data are entered.

Module 4, Setup and Default Values, allows for a variety of adjustments, including scaling of the line drawing and plots, choice of operating type, saving and recalling setups, and other options.

Module 5, Travel Times and Spacings, shows the travel time along the line schematic for each spacing as well as the overall operating time and operating speed.

Module 6, Time-Distance Plots, generates the time-distance plots. It is possible to superimpose skip-stop and local operations on the same plot. Changing "direction" to "2" in Module 4 will draw the mirror images. When two-zone operation is selected, both zones will be plotted together.

Module 7, Scheduling, calculates steady-state fleet size for a given headway and desirable headway for a given passenger flow. Nonclock headways will be neither computed nor permitted for any headway greater than 6 min.

Module 8, Operations Chart, requires an information tabulation for each train. This is accomplished by creating two Lotus 1-2-3 spreadsheets, one for each train direction. For each train, the planned dispatch time (in seconds after the start of the chosen 2-hr block to be plotted), type of operation (local, skip-stop A, or skip-stop B), and any station to have delays and the amount of delay (or negative delay) must be listed. The outputs are an operations chart in Hewlett Packard Graphics Language (HP-GL) format for later plotting by a high-resolution plotter and a tentative schedule. The schedule shows dispatch time, three intermediate computed (checkpoint) times, and run completion times for each train. Figure 8 shows a schematic of how Module 8 interacts with input and output external to the Turbo Pascal program.

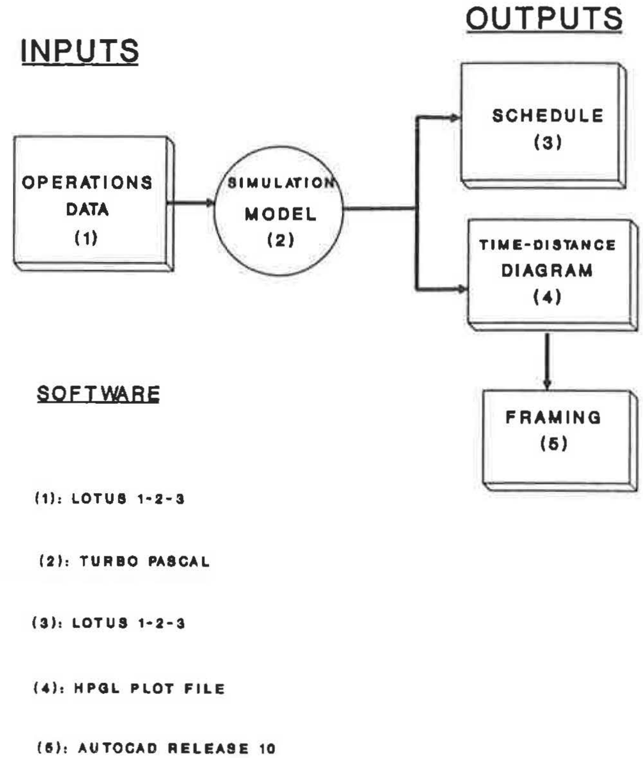

FIGURE 8 Schematic of simulation process.

TESTING AND CALIBRATION

The operating characteristics and alignment of the MFSE were used to test the program. Significant variances in driving times were found on the MFSE for what may superficially appear to be a highly deterministic process. Thus, statistical estimators for the parameters were required instead of fixed values.

Initial Results

Initial running of the program using established estimates of rolling-stock parameters and known speed restrictions indicated that end-to-end running time was within 1 min of the scheduled running time for both local and skip-stop operations. However, the schedule is not a reliable basis for calibration, given the stochastic operations of real trains. Moreover, in the test case it was necessary to simulate some intermediate point-to-point running times accurately as well.

Three intermediate checkpoints were created for point-to-point calibration. The published schedule has only one intermediate checkpoint and no statistical information regarding adherence to schedule. Thus, it was necessary to collect representative data.

Data Collection and Normalization

The calibration data were collected on a regular weekday during the peak travel period 3:30 to 5:30 p.m. A summary of results for eastbound skip-stop trains is shown in Table 1, which contains the number of trains (N), travel time between checkpoints (X), and the standard deviation (σ) values for A and B trains.

The mean values were used as target values for calibration, and the standard deviation is an indicator of the scatter of observed driving times.

TABLE 1 STATISTICAL SUMMARY, EASTBOUND SKIP-STOP TRAINS

TRAVEL TIME SURVEY SECTIONS	N_A	X_A (min)	σ_A (min)	N_B	X_B (min)	σ_B (min)
69th ST - 30th ST	15	11.75	.32	15	11.58	.59
30th ST - 8th ST	14	5.39	.79	14	5.83	1.23
8th ST - ALLEGHENY AVE	13	11.80	.93	13	11.88	.77
ALLEGHENY AVE - BRIDGE-PRATT	11	7.76	.69	11	7.63	.46
OVERALL TRAVEL TIME	11	36.70	1.21	11	37.00	1.70

The westbound trains have similar times, except that the time from the 8th Street checkpoint to the Allegheny Avenue checkpoint is consistently slower. The lack of symmetry is due to the different signal speed control in the two directions. Rather than make a separate speed profile input for the westbound direction, the mirror image of the eastbound data, corrected by adding a delay at one stop to all trains in this direction, was used.

Adjustments and Modifications

Four main variables can be used to calibrate the operating times: acceleration rates, deceleration rates, dwell times, and average cruising speeds.

Acceleration and deceleration rates used were based on empirical measurements. They were not used for further calibration but were treated as constants ($\bar{a}$ = 0.76 m/sec^2, $\bar{b}$ = 0.76 m/sec^2) for the whole line. This was done because the largest source of deviation in travel times was different speed profiles used by different operators. These deviations are much larger than those caused by gradients or other factors. The dwell times were not varied for calibration, because they are consistent and deterministic in the off-peak and have a consistent lower bound and little scatter even in the peak.

To preserve the accuracy of any later sensitivity analyses, it was important to attribute time to each regime (accelerating, braking, cruising, and standing) as well as the available information allowed. Therefore, the key variable for calibration was the average cruising speed. It could readily be adjusted to provide the mean operating time for a spacing and compensate for a variety of speed profiles. This was done by selecting an average cruising speed that gave an acceptable overall travel time (usually the mean value) between stations, even if the actual speed profile was not modeled precisely. After some minor corrections to a few sections, primarily those with tight radius curves, the model gave results close to measured mean running times, both checkpoint to checkpoint and overall.

APPLICATIONS

For rail rapid transit lines like MFSE, in which the headways are short and driving times are stochastic, even short delays can cause major disruptions. Computerized scheduling can be useful in such cases. Some suggested applications follow.

Normal Schedule Analysis

By superimposing various "shadow" lines over the scheduled operations chart, it is possible to visualize the potential for conflict. A shadow is an imaginary line representing the envelope of time within which a certain percentage of trains will lie. Without checkpoints, the envelope will grow broader as the distance traveled down the line increases. With the addition of checkpoints, it is always possible to put the early trains back on schedule. A certain percentage of trains behind the scheduled time will also catch up to schedule. The percentage of on-time trains increases as the scheduled checkpoint departure time is further delayed (i.e., as "slack" is added to the checkpoint). The trains that depart on schedule will again scatter, whereas the late trains will also scatter, but with a bias toward being equally late at the next checkpoint. After the first checkpoint, the distribution becomes complicated because of the trains already late, but it can be approximated. Figure 9 shows one standard deviation, but in practice any percentage can be specified. (One of the main functions of Automatic Train Operation, or ATO, is to remove the scatter caused by variation in drivers.)

When shadow lines are drawn for each train, it becomes possible to visualize which trains at which locations are likely to have conflicts. The distance between the late and early lines of two consecutive train runs indicates how much delay can be accommodated for a given train run and location before the delay affects the schedule. How and when to delay or speed up following trains to recover most quickly from disruptions, while minimizing the possibility of inadvertently creating new ones, can easily be visualized. Any postulated situation can be introduced from the input spreadsheet, and proposed responses can be sketched onto the operations chart.

When trackage is shared with another route, a time-distance trajectory from that other line can be overlaid along the common section to assess how early or late the merging train can be without disrupting the schedule.

A time-distance operations chart is convenient for other uses as well, such as calculating the fleet size required at any time.

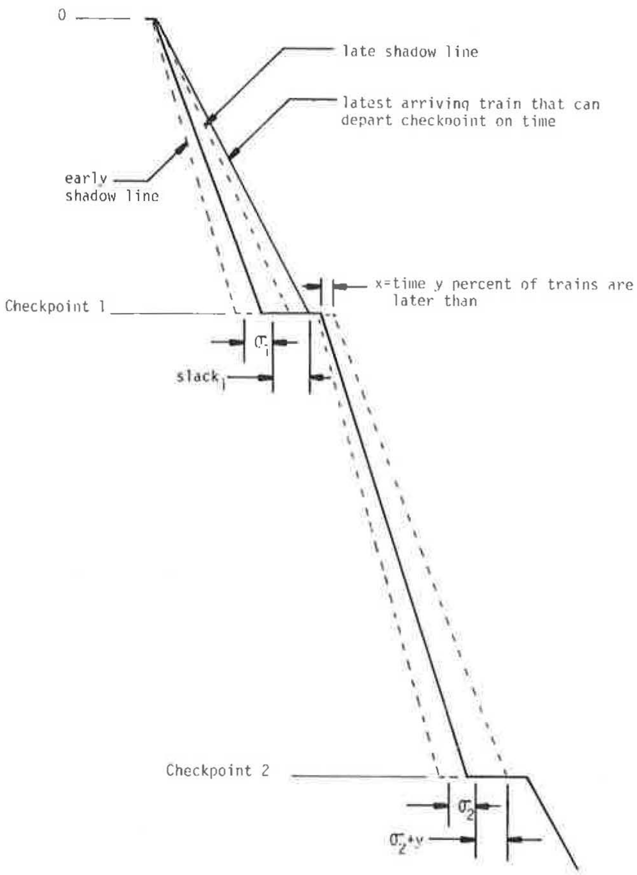

FIGURE 9 Shadow lines showing train dispersion.

Test Application: Single-Track Operations

Although the Huntingdon station (Station 8) will be closed to passengers during the reconstruction, for modeling purposes it was assumed to remain in existence as an AB station. The Somerset station (Station 7), at the eastbound side of the section, was converted from a B to an AB station to minimize the inconvenience to the regular users of the Huntingdon Station. Trivial changes to the input file were made to incorporate these changes.

The worst case—the afternoon rush period when the eastbound track section is removed—was chosen for modeling. In this case, the maximum number of eastbound trains is required, but each eastbound train must cross to the westbound track and back again, consuming extra time. The trains were limited to approximately 24 km/hr (15 mph) on the crossovers.

The strategy for providing the desired capacity is to alternately platoon trains in the eastbound direction. That is, two eastbound trains cross for one westbound train. Such asymmetric platooning, however, would not have been considered if ridership volume required an equal number of trains to be operated in the opposite direction at the same time.

The westbound trains can be modeled as making a normal stop at Station 7 but passing through Station 8. This is done by negating the time lost because of stopping at Station 8 by adding a negative delay on the input spreadsheet. The negative delay is calculated by using Equation 5 and is

$$T_{p_8}(WB) = -\frac{v_8}{2}\left(\frac{1}{\bar{b}}\right) - \frac{v_7}{2}\left(\frac{1}{\bar{a}}\right) - t_{s_8} = -26 \text{ sec} \quad (9)$$

A change in slope will be seen in the trajectory on each side of Station 8 to reflect the different average speeds.

The modeling for the eastbound trains is more complicated. Each train in the platoon slows down to 24 km/hr (15 mph) and proceeds directly over the crossover. This saves the entire time lost due to stopping, which, calculated in a similar manner as above, is about −26 sec. However, traversing the crossovers requires about 30 sec more than maintaining speed and not using the crossovers, so the net penalty for each train in the platoon is about −26 + 30 = 4 sec.

The penalty values are entered in the input spreadsheet for each affected train, and the modified operations chart is generated. If it is possible to generate a chart with no obvious conflicts (i.e., it appears physically possible given some relative adjustment of dispatch or checkpoint departure times), the tentative operation must be further checked to ascertain that it is practical. These considerations will not be discussed here, but they include such issues as selecting a checkpoint closer to the single-track section, time allowances for signals to clear, and so forth. Figure 10 shows a feasible operations chart for the critical period. Note the closely spaced pairs of lines corresponding to platooned operation.

Variable Operating Conditions

Once a baseline configuration is established, it becomes easy to perform sensitivity analyses on the various parameters. The one weakness with this type of model is that it does not give a meter-by-meter speed profile. Thus it is not usable for analysis of dynamic or track forces. The speed profile along a section must be assumed a priori and the average values then computed, so some preliminary analysis may be required. Once they are obtained, changes to operations or rolling stock can be quickly analyzed.

CONCLUSIONS

The major conclusions to be drawn from the work described here are as follows:

1. The removal from revenue service of the section of track 599 m (1,964 ft) long on the MFSE line does not necessarily require a reduction in the number of trains operated with both tracks in service. To maintain a high level of service during the peak-of-the-peak window, however, it is necessary to apply a platooning (fleeting) type of operation.
2. Simulation programs provide a low-cost, innovative technique for analyzing train operations and scheduling. The mathematical formulations used are standard kinematic relations, easily derived or found in textbooks. The software employed (Turbo Pascal, Lotus 1-2-3, and AutoCad) are widespread, off-the-shelf retail packages.
3. Transit and railroad companies could easily use computerized time-distance diagrams to accomplish various scheduling needs and easily test adjustments or variations that presently require manual computations.

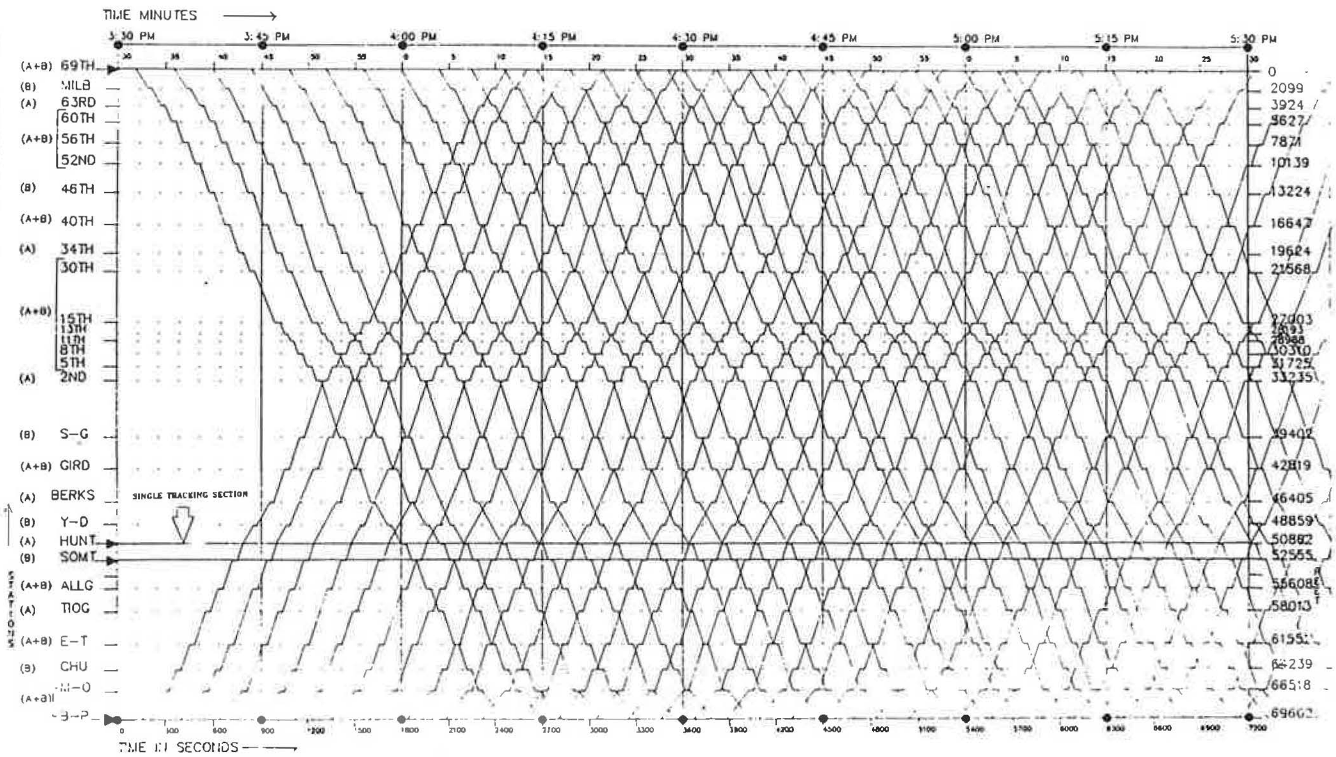

FIGURE 10 Example schedule for MFSE line with both Huntingdon and Somerset stations open: 2-hr time-distance operations chart (3:30 to 5:30 p.m.), proposed single-tracking schedule.

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The authors are solely responsible for the content and conclusions discussed in this paper. These may not represent the official views or policies of the University of Pennsylvania or the Southeastern Pennsylvania Transportation Authority.

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Transit Railcar Quantities: Scale Economies

JONATHAN H. KLEIN

The effect of increasing size order on purchase prices of railcars is examined using data obtained from suppliers in a survey by a major transit authority. A distinction is made between short-run price and cost, the former being borne by the buyer and the latter by the supplier. The data, consisting of average price points, are converted into marginal cost curves. The analysis indicates that most economies of order size seen by the buyer as per car savings are realized by the time orders reach 60 to 90 cars. Virtually all purchasing economies are reached by the time orders reach 200 cars. Further manufacturing economies of scale, if any, will likely accrue to the suppliers. A corollary is that economies thought to result from the purchase of "off-the-shelf" cars may not exist in a significant way.

A major problem in rail passenger systems is the rapidly escalating purchase cost of railcars. In the past few years, attention has been directed toward understanding the factors in a railcar's purchase cost and how to set the parameters of these factors to minimize the cost. This effort has recently been expressed in UMTA's railcar cost containment initiatives. One such factor is the quantity of cars ordered at a single time.

The effect of order quantity, or "lot size," on the purchase cost of passenger railcars will be discussed. The degree to which the cost can be expected to decline, if it declines at all, will be determined. If the cost declines, what decision-making rules can be developed to guide car purchasers? The validity of current beliefs about the relationship between costs and order quantity and how the validity of those beliefs should govern procurement will be examined.

A review of some of the literature suggests that larger order size reduces per car costs (*1,2*). A study for UMTA by Dynatrend suggests, on the basis of a statistical analysis of historical contract prices, that costs for quantities of more than 46 cars are significantly less than for quantities of less than 46 cars (*3*). Other studies simply assume that standardization will result in lower car purchase costs, presumably because standardized (off-the-shelf) cars represent, as an aggregate, a large order (*4*).

ECONOMIES

It is reasonable to believe that increasing the order size reduces the cost of a passenger railcar. It is thought that the manufacture of railcars ought to exhibit economies of scale; therefore, the average and marginal costs of cars should decline as the quantity produced increases. The economies of scale are thought to arise from three causes:

1. For a given manufacturing technology or design, setup and overhead costs are absorbed over a greater volume.
2. For a given manufacturing technology, the "learning curve" phenomenon reduces the unit cost of additional units.
3. As order quantity increases, the manufacturing technology shifts to a higher setup cost and lower unit cost method, yielding a lower total cost for large volumes.

SURVEY AND DATA

But is this belief true? An opportunity to test the hypothesis that lower per car costs result from larger order quantities arose in the large amount of survey data gathered by the Southeastern Pennsylvania Transportation Authority (SEPTA) during its Railcar Cost Containment Program sponsored by UMTA in 1989 and 1990.

In this study, car builders, their system suppliers, and consulting engineers were surveyed to determine what they "thought" the effect of various parameters would be on the cost of cars. Each respondent was asked to estimate qualitatively and quantitatively the change in cost resulting from a change in a specific aspect of car procurement. The changes included different propulsion controls, choice of materials, and warranty duration, for example. Each respondent was also asked how the cost would vary with order size.

The response data were initially taken at face value. The data were provided by 24 firms: 11 car builders; 7 subcontractors, or systems suppliers; and 6 consulting engineering firms. Every major car builder except Kawasaki/NIAC responded to the survey. Though the sample population is not large, it encompasses the great bulk of suppliers. All respondents were asked to keep one car in mind: a 75-ft-long, stainless steel electric multiple unit with the subsystems typically used on cars of newer North American systems, such as those in Los Angeles, Baltimore, Miami, Atlanta, and Washington, D.C.

Before the survey responses are examined, a distinction between cost and price must be made. The two are not necessarily equal and, in fact, their difference is equal to profit (or loss). Increasing the quantity of cars ordered may reduce a supplier's costs, but it may not result in lower prices for a buyer. For this analysis, it will be assumed that the survey responses are in terms of prices, because that is what UMTA and SEPTA inquired about. In the long run, cost and price

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may approach one another. However, most buyers of cars place their orders in the short run.

Each respondent was asked to speculate how much the price of a car might be reduced or increased if a base order of 50 cars were changed to 100 cars, 200 cars, or approximately 30 cars. The price changes were expressed as a percentage change. Some of the changes were expressed as ranges (e.g., 3 to 6 percent or 7 to 10 percent). From the responses, the average car price for each order quantity can be calculated. The marginal price of the additional cars can be calculated from the average price. These marginal price points describe a marginal price curve. The slope of the curve is the rate at which prices change. When the slope approaches zero, most of the economies have been realized.

For example, one respondent, a consulting engineering firm, estimated percentage price changes for changes in order size as given in the following table. The price changes are expressed as a percentage change from the base price, whatever that may be, say, $1,000,000.

Order Size	*Change from Base (%)*	*Average Price of Car ($)*	*Marginal Cost of Car ($)*	*Marginal Change (%)*
30	+10	1,100,000	1,200,000	+20
50	base	1,000,000	base	base
100	−10	900,000	800,000	−20
200	−15	850,000	800,000	0

The choice of a base near the midpoint of a series creates some computational clumsiness.

ACTUAL COST CURVES

The marginal and average price curves described by these points follow the expected shape of the classic curves. Computer-generated fits of the points yield curves of declining prices best approximated by a logarithmic function. These curves are displayed in Figure 1 for one of the respondent car builders. A common computer statistical package converted them as shown in Figure 2.

A regression analysis on the entire population of respondents' points produced the following equation:

$$P_q = \$1.57 \text{ million} - \$0.137 \text{ million} \times \log Q$$

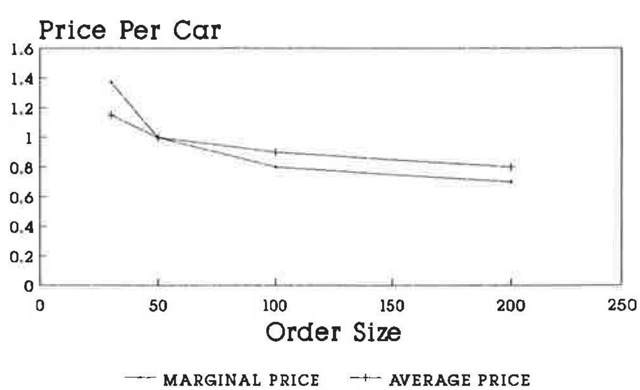

FIGURE 1 Cost curves for Car Builder A (marginal price and average price).

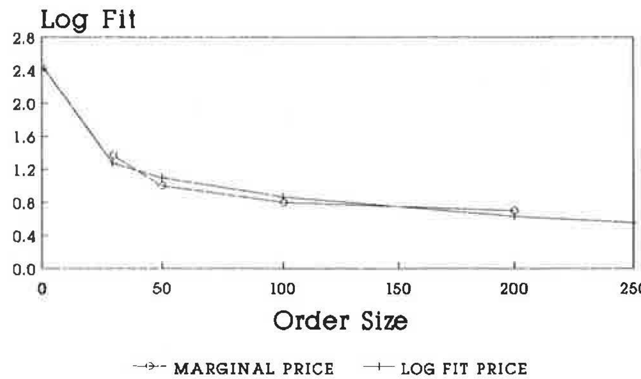

FIGURE 2 Cost curves for Car Builder A (marginal price and logarithmic fit price).

where P_q is the marginal price of the qth car and Q is the total size of the car order. The total order price is the integral of the equation over the domain of the order quantity. The R^2 of only 0.55, however, means that the predictive value of the equation is limited.

VARIABILITY IN SLOPES

However, this last result is deceiving. An inspection of the raw response data indicates the existence of two distinct populations. The first consists of firms who claim that their curves decline at a declining rate (i.e., that prices decline as order size increases, up to a point). This is expected and is shown for one car builder in Figure 1. The second consists of firms whose responses yield virtually flat curves, as shown for another car builder in Figure 3. These firms claim that prices are inelastic over order size.

A statistical averaging of the two populations is clearly inappropriate. But an inspection of the two populations is illuminating.

The difference in slopes between the car builders in Figures 1 and 3 is curious. Both firms are located in the same country. They presumably are talking about the same general car at the same time. They claim to be able to produce a wide variety of designs, and, indeed, they produced nearly identical cars at one time or another for the Philadelphia market. Why does Car Builder B claim that prices, or costs, do not vary over

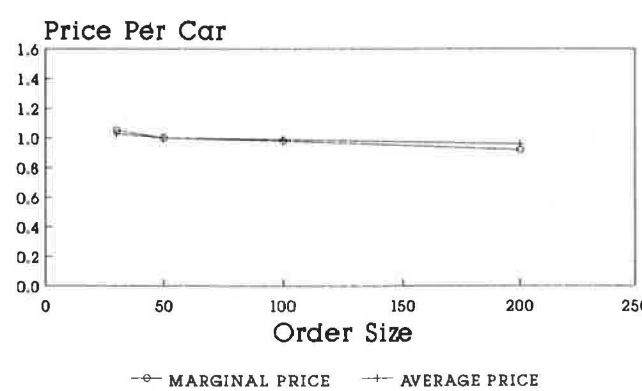

FIGURE 3 Cost curves for Car Builder B (marginal price and average price).

production runs varying by an order of magnitude, whereas Car Builder A's response yields the expected decline in price as order quantity increases?

The following explanations, however likely or implausible, come to mind to explain the horizontal response of Car Builder B:

1. Car Builder B does not intuitively or formally understand its own cost and price structure and responded in confusion (i.e., it is unsophisticated).
2. Car Builder B understands its cost structure but chooses not to present UMTA or a potential customer with realistic data (i.e., it is deceptive).
3. Car Builder B has no manufacturing expertise and uses no elaborate tooling. Hence, it never moves along the learning curve, or it has no setup or design cost to absorb.
4. The two firms differ in their production experience and may be describing different parts of the same production curve.
5. Some combination of the above explanations applies.

An exploration of these explanations yields a provocative conclusion: specifying an off-the-shelf car may not result in a lower car price. But before exploring the path leading to this counterintuitive conclusion, other implications of the possible explanations must be reviewed.

It is possible that the respondents do not understand the conceptual basis of the questionnaire. This is Reason 1. It is plausible. Some of the survey responses generated inconsistent data points—the average and marginal prices declined with order size and then rose. After all, strategic economic modeling has not been a strong point of the car supply industry. This may partially explain the demise of some of its members.

Reason 2, duplicity, is also possible. Regrettably, experience suggests that duplicity and commercial mendacity are accepted attributes inside some firms. Furthermore, firms may view cost structure and pricing decision making as highly proprietary information. Consequently, it would be imprudent to dismiss the possibility of a firm deliberately submitting misinformation to the client community.

Reason 3 may be partially true. The idea that a firm has no discernible learning curve or tooling costs may be dismissed. It is unlikely that such a firm would survive. However, a firm may have low design and tooling costs if it purchases existing designs or produces only designs it has made before. In these cases, product research and development costs are low to begin with, leading to fewer costs to be absorbed over volume.

This phenomenon leads into Reason 4: the two firms are actually describing different parts of the typical production curve. Car Builder B's entire output over the past 6 years has largely consisted of two designs. Both designs were purchased from other car builders that had successfully constructed these designs before. Car Builder B's efforts in manufacturing to these designs have been successful. Efforts to secure orders for other designs have been less successful. In other words, Car Builder B is well along a production experience curve. Because almost all its new orders are for cars it has already built, it may not view an order for 50 cars as 50 cars of a new type, but as 50 cars on top of the 500 or more of virtually the same type of car that it has built before or, in fact, may be in the midst of building for another customer.

This explanation is supported by an examination of the remainder of all respondents' data. Figure 4 shows the distribution of all respondents' price elasticities as approximated by the percentage change in prices from the smallest to the largest order size. Car builders typically believe that there are significant economies in order size. But their subcontractors for brakes, propulsion, door controls, and so on are less inclined to this belief. These component suppliers, however, produce more of a standard product. For example, Chicago Transit Authority (CTA), Massachusetts Bay Transportation Authority (MBTA), and SEPTA rapid transit cars use the same General Electric SCM II propulsion controls, though with minor variations. But the variation between the CTA, MBTA, and SEPTA car body structures is much greater than that between the car propulsion controls. Consequently, the car builders frequently must start at the beginning of the learning curve with each new customer's order. Suppliers like General Electric frequently do not start at the beginning, but are well along the curves.

The situation is analogous to new-home construction. Each kitchen may be customized. Each kitchen appliance is not. The building contractor believes 20 homes with the same design to be a long production run offering significant economies. However, the appliance manufacturer sees 20 appliances of the same design as routine.

The consulting engineering community's view appears to cover the entire spectrum of opinion and, taken as a group, is inconclusive. This is not surprising.

"OFF-THE-SHELF" PARADOX

It is often thought that specifying an off-the-shelf car results in paying a lower price for each car, especially if the buyer is purchasing only a small number of cars. The foregoing analysis can be further developed to show that this is not necessarily the case. It is possible to specify a general-purpose car that only approximates requirements—to obtain a lower price—and yet pay a cost close to that of a customized car.

This is how it happens. Say a car builder has an order for 100 cars from Buyer A. It bids or negotiates a price on the basis of its total cost of producing 100 cars of this design.

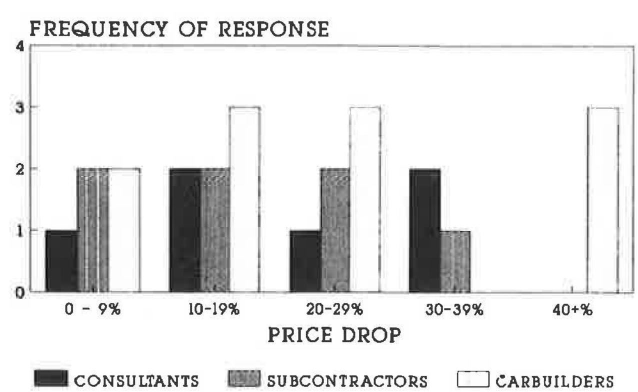

FIGURE 4 Price drop due to increasing order from 30 to 200 cars.

Buyer B wishes to order 50 cars. It wants cars customized to its unique needs. However, to economize, it solicits prices using Buyer A's design. Because the car builder can move along the cost curve to the right, that is, from 100 to 150 cars, its marginal cost declines.

But it may not pass the cost reduction along to Buyer B. It will probably charge Buyer B what it charged Buyer A, thereby retaining all the savings for itself. Recall that price does not equal cost. The difference between the two is profit, and the car builder tries to increase its profits.

If the car builder did lower the price to Buyer B, one can well imagine the protest from Buyer A. Buyer A bought 100 cars and paid more than Buyer B, which bought only 50. To Buyer A, this is manifestly unfair.

Buyer B might still save a significant amount. All things being equal, the price paid for 50 cars will be the lower price paid for 100-car orders. But the car builder's objective is to make sure all things are not equal. It wishes to push the price back toward the 50-car level. It will not try to equal the 50-car price. If it does, it opens up the market to other car builders. But it will try to raise the price to near this point.

It does so by finding a commercial pretext for making what was an off-the-shelf car suddenly customized or different. The difference may be only a routine product evolution or improvement, such as a relocated electrical apparatus locker or modernized door controls. It may be accelerated delivery. In any case, the objective of the car builder is to persuade the buyer that these differences, costing thousands, are worth tens of thousands. A capable buyer may be able to resist these commercial maneuvers if it is determined and informed.

COMPUTED PRICE BREAK POINT

A useful heuristic can be drawn from the results of the survey. The computed average prices for the 11 respondent car builders are given in Table 1, in which each car builder is identified by a letter.

Inspection indicates that most car builders see a leveling in average prices around an order size of 100 cars. This is not surprising. Most orders are for less than 100 units, and these are frequently not 100 identical units. Often the order is composed of cabs and trailers, married pairs, or other assortments of a design. Therefore, if a car builder cannot achieve most production economies before 100 cars, it is reduced to bidding on only a few rapid transit car orders a decade. To survive, suppliers must evolve a manufacturing approach that flattens the cost curve before 100 cars of a design is reached.

TABLE 1 CAR BUILDERS' AVERAGE PRICE (BASE ORDER PRICE = 1.00)

	Order Size			
Carbuilder	30	50	100	200
A	1.15	1.00	0.90	0.80
B	1.03	1.00	0.99	0.96
C	1.21	1.00	0.95	0.89
D	1.15	1.00	0.90	0.80
E	1.07	1.00	0.92	0.88
F	1.07	1.00	0.92	0.90
G	1.08	1.00	0.91	0.89
H	1.06	1.00	0.96	0.94
I	1.06	1.00	0.97	0.95
J	1.02	1.00	0.96	0.95
K	1.02	1.00	0.98	0.97

As a practical matter, increasing the size of car orders to 100 cars can substantially reduce the price, perhaps by 10 to 30 percent. Increasing the order size from 100 to 200 may reduce the price by up to another 10 percent. Orders of more than 200 cars will not result in significantly lower prices, although they may result in significantly higher profits (or disastrous losses) for the supplier.

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Evaluation of the CalTrain Feeder Shuttle Program Serving Suburban Workplaces

ROGER HOOSON

A 2-year-old project to provide small-vehicle feeder services between San Francisco Peninsula commuter train stations and suburban employment centers is described. The typical passenger is well educated, a new train rider, and could have driven a car to a free parking space at work. The early planning process leading to development of contract specifications and bidding is outlined. Operational experience, ridership growth (including the effects of the October 1989 earthquake), marketing activities, the results of a passenger survey, and funding are described. Other shuttle services on the San Francisco Peninsula and some examples from other U.S. cities are assessed.

The California Department of Transportation (Caltrans) manages the CalTrain commuter rail service, which runs 47 mi along the San Francisco Peninsula between San Francisco and San Jose. In September 1988, Caltrans initiated a small-vehicle feeder service between suburban train stations and largely new employment centers 1 to 4 mi away. The number of routes operated grew from three initially to seven in late 1990; almost 500 boarding riders per weekday are carried.

Service is competitively contracted and is provided by relatively new, high-roof van conversions with 21 to 25 padded, forward-facing seats. Vehicle exteriors display the CalTrain logo.

One vehicle is operated on each route during peak hours only, toward employment centers in the morning and toward train stations in the evening. Four to six morning trips and four to six afternoon trips are operated per route, all timed to meet trains. A total of 66 weekday trips are provided.

No fare is charged because of the shortness of the trip and the expected high administrative cost of fare collection, which could absorb much of the revenue generated. Also, most shuttle passengers are new to CalTrain, and their train fares improve CalTrain's revenue/cost ratio, because there are virtually no marginal train costs involved in serving this number of new passengers.

The service currently costs an average of $54,000 per route annually. Funding comes from private employers and developers (28 percent), local transit districts (25 percent), Caltrans (25 percent), and cities served (22 percent).

The typical passenger is well educated and could have driven a car to work instead of riding transit. Most passengers did not use CalTrain before the shuttles were introduced.

This paper discusses all elements of the Caltrans program and provides a brief perspective on other suburban shuttles connecting with CalTrain, as well as a few similar programs elsewhere in the nation. It concludes with a short assessment of the Caltrans program and a suggestion for the future.

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SERVICE ORIGINS

In its 1987 session, the California legislature passed Assembly Bill 1675, which gave Caltrans $250,000 for a CalTrain feeder demonstration program. The legislature wanted to promote competitive contracting in the provision of transit service, and Caltrans staff believed that CalTrain suburban workplace feeders would improve the train's accessibility, like the long-established shuttle connection to San Francisco's financial district.

In early 1988, Caltrans staff met with planners for San Francisco Peninsula transit districts, and a number of candidate shuttle routes were chosen. Selection criteria included number of employees served, their home locations, and distance of the employment area from a train station (vehicles must make a round trip in 25 min at most to meet trains every half hour). Only areas without existing transit links to stations were considered. Transit districts were receptive because, despite public pressure to add lines to these areas, they could not afford to do so.

Next, the local assemblyman sponsored a meeting for businesses and cities in the affected areas. A brief slide show describing CalTrain and the shuttle concept was presented by Caltrans staff; key benefits to companies were outlined (Figure 1). Caltrans made several other presentations to employer groups.

On the basis of financial commitments from businesses and cities to contribute one-third of the estimated cost of each shuttle route, Caltrans selected four routes for start-up later in 1988, two in San Mateo County and two in Santa Clara County.

THE CONTRACTING PROCESS

In writing the initial contract specifications, Caltrans staff consulted requests for proposal (RFPs) from several other agencies, including the Bay Area Rapid Transit District's RFP for its BART Express bus service and a Los Angeles RFP for residential shuttles. Because Caltrans was to issue a simple invitation for bids, rather than a full RFP, it was necessary to be explicit about driver conduct, vehicle maintenance, reporting requirements, bonding, insurance, indemnification, and other matters.

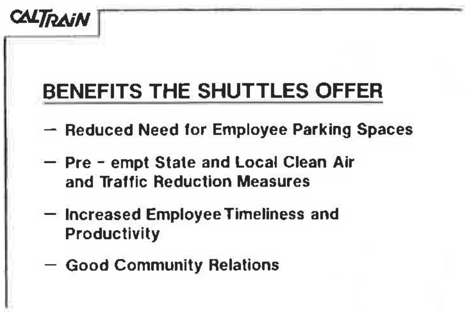

FIGURE 1 Employer marketing graphic.

In the first contract, vehicles were required to have 19 to 25 passenger seats, interior headroom of at least 75 in., a gross vehicle weight rating less than 18,000 lb, an age of less than 3 years with odometer mileage less than 75,000, and a radio link to a central dispatcher. With more than 20 passengers riding some trips, the current contract effective July 1990 requires 21 to 30 seats and odometer mileage less than 60,000.

The specifications are intended to secure comfortable, reliable, and intimate vehicles that can traverse company parking lots and make tight turns. Vehicles must be able to display the CalTrain logo on each side, and the successful bidder must provide significant additional vehicles and service hours if Caltrans wishes to expand service.

The contract requires that vehicles be kept clean and their components in good working order. If the operation is shut down by the California Public Utilities Commission for safety reasons, Caltrans can assess a penalty of $500 per vehicle per day. Drivers must carry an accurate timepiece, be courteous, drive safely, and keep a log of passenger boardings by trip and delayed or missing services.

A performance bond or letter of credit in an amount sufficient to pay a substitute operator for 2 months is initially required of new contractors (reduced to 1 month after a satisfactory trial period), as is a certificate of insurance providing at least $5 million coverage per occurrence. The successful bidder must also indemnify Caltrans and the county-level transit districts that finance the train service.

An incentive for on-time operation was included in the original contract. It provided that if 95 percent of trips arrive at their last drop-off point within 2 to 3 min of schedule time in a given month, the contractor was eligible to earn 3 percent extra. However, the successful bidder apparently believed that the record keeping necessary to earn this bonus would be too time-consuming and therefore did not apply for it. Because Caltrans subsequently believed that this provision could skew a contractor's record keeping, the agency did not include it in the specifications for the second contract.

Service providers prefer contracts of at least 3 years to reduce vehicle lease-purchase costs. However, because of the Caltrans project's initial demonstration status, an unfavorable 1-year term was applied to the first contract (an option to extend for 10 months was subsequently exercised). The current contract runs for 2 years with an option to extend, the longest possible period given that whether Caltrans will continue to manage CalTrain is uncertain.

Because 20 mi separates the northernmost and southernmost routes, Caltrans allows bidders the option of contesting only half the service. Caltrans selects the responsive bid or combination of bids that results in the lowest total cost.

For both contracts, a list of about 20 potential bidders was assembled by referring to both a directory issued by the regional planning commission and the Yellow Pages (the successful bidder is listed only in the Yellow Pages).

The first contest in mid-1988 attracted only two bids, apparently because of the contract's short duration. The longer second contract yielded five bids. Both contests were won by the same immigrant-owned firm, employing mostly immigrant drivers. The rate was $42/veh-hr for the first contract and $50/veh-hr for the second. The $50 bid is based on an average of only 4 hr 17 min of service per route per weekday and results in an annual cost per route of $54,000.

INITIAL OPERATIONS

The first three routes started in September 1988, and the fourth started in November after corporate contributions were secured. About 1 week before service began, Caltrans, city, and contractor staff rode the shuttle vehicle on the proposed route during rush hour. Before service started, a supervisor showed drivers the route once more.

At first, some drivers had difficulty running precisely to schedule and conversing with passengers in English. Reasonable English fluency was not required in the first contract (it was added to the second). Passengers who started riding some time after a route started had an advantage because they could learn details from veteran riders. Meanwhile, some (but not all) drivers improved their language skills.

RECENT CONTRACTOR PERFORMANCE

Since the start-up period, the contractor has provided reliable service. Trains are rarely missed, and breakdowns are infrequent. The 2¼-year-old operation has been essentially accident free. Vehicles have passed all California Highway Patrol inspections. Vehicles are kept clean. After the firm won another major contract recently, it supplied Caltrans with new vehicles that exceed specifications.

Remaining minor issues include the accuracy of some ridership reports, occasional accounts of drivers running slightly early or late, and some new riders' complaints about drivers' English fluency (though informal passenger polling suggests that this is not an issue for most). The contractor has requested a 4 percent rate increase to cope with higher fuel costs since August 1990, and the firm's insurance company is attempting to raise its classification.

Caltrans recently decided to place postpaid customer comment cards in vehicles. So far, 90 percent of comments have been complimentary.

RIDERSHIP

In early 1989 a ridership plateau of about 200 daily boardings was reached, and growth was unimpressive (Figures 2 and 3). Vehicle trips that averaged fewer than two passengers were discontinued. However, concerted corporate outreach efforts,

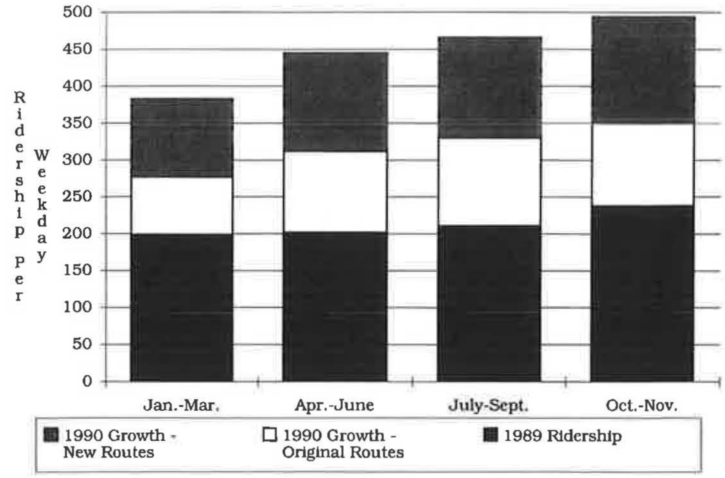

FIGURE 2 CalTrain Shuttle ridership.

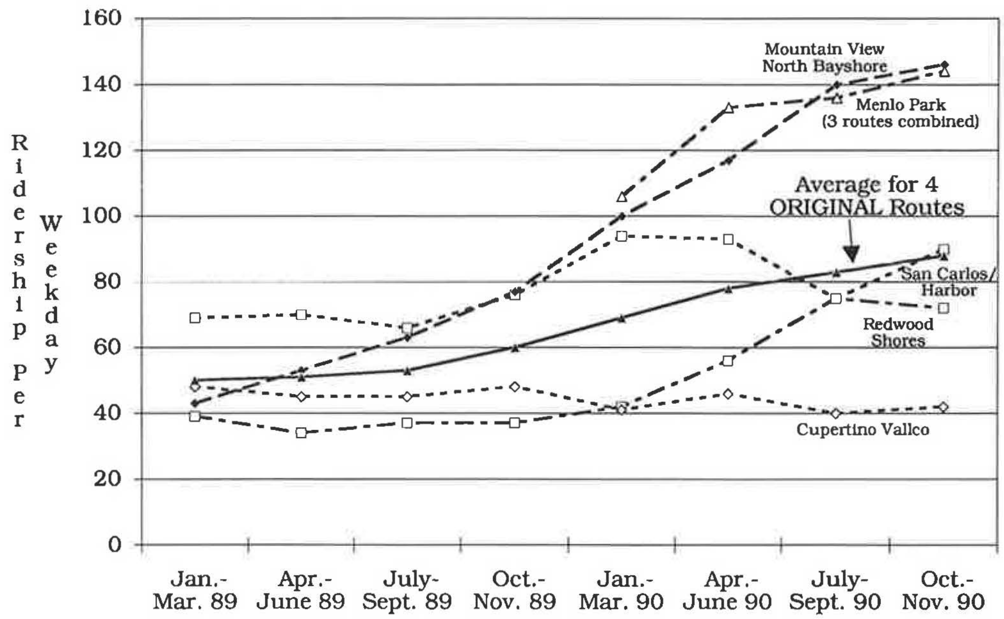

FIGURE 3 CalTrain Shuttle ridership by route.

including poster and schedule distribution, gave the Mountain View route a major boost; ridership has not stopped growing since. A large electronics company mentioned the operation in its employee newsletter, and a land developer published a front-page color photograph of the vehicle in its glossy quarterly, but ridership did not increase much on these routes. Some companies, perhaps content to support "socially responsible" transportation regardless of use, may not have made the effort necessary for major rider gains in the face of abundant free parking and dispersed employee trip patterns.

An unexpected natural calamity proved to be the boost the shuttles needed. The October 1989 earthquake closed freeways and bridges and led to renewed corporate publicity for the service. Mountain View and San Carlos ridership increased rapidly, despite a contraction of Mountain View service to only one vehicle instead of two, with 41 percent fewer runs made.

An equally significant effect of the earthquake was the rapid introduction of two new routes in Menlo Park (to one of which the other Mountain View vehicle was assigned), followed by a third route there in March 1990. The earthquake caused a previously reticent major employer to commit funds and to pressure the city and other employers to do likewise. Ridership on these services is included in Figures 2 and 3 starting in the first quarter of 1990.

Largely because of postearthquake ridership growth and new routes, patronage in the entire fourth quarter of 1989 (including December) increased 44 percent over the third quarter. By the second quarter of 1990, daily ridership of 445 was more than double that of a year earlier; it was up 50 percent on the original routes. October-November 1990 ridership of 494 continued to be more than double the 238 of a year earlier, and the Mountain View route experienced a capacity problem.

More than half the daily ridership is in the morning; some commuters appear to get rides or walk in the afternoon. Ridership per vehicle trip now averages 7.5; for the four original routes it is 8.3. The most heavily used trips made by the Mountain View and San Carlos shuttles carry more than 20 passengers.

Despite general ridership success, one route has not done well. The location of Cupertino's Vallco Research Park near the present south end of the CalTrain corridor means that the train is a realistic option only for commuters who live to the north, and few new employees can afford to do so. Those who do live there find that the uncongested I-280 freeway is a tempting alternative. A planned southern CalTrain extension to new housing in south San Jose, Morgan Hill, and Gilroy should help to address the problem.

MARKETING

Caltrans is responsible for most shuttle publicity, but cities and a major developer have assisted with corporate outreach. Because the shuttles serve a limited set of employers, marketing efforts have been concentrated there. Contacts with some employer representatives had been made when the initial routes were chosen, but additional names were obtained before service began.

The marketing agency used by Caltrans developed 11-in. × 17-in. posters for company bulletin boards (size reduced for Figure 4), distributed cards that could be returned for a free CalTrain round-trip ticket, and supplied schedule holders for Caltrans-designed shuttle timetables and route maps. Both the poster and the schedules show the shuttle vehicle.

Another key marketing tool is the CalTrain logo on vehicles. Weatherproof boards, about 5 ft long, are installed in contractor-supplied metal frames on vehicle sides below the windows. The display is relatively subtle but clearly marks the vehicles as part of the CalTrain service.

PASSENGER SURVEY RESULTS

Caltrans conducted its second survey of shuttle riders in May 1990. For the four "mature" routes operating more than 1 year, key results include the following:

- Though the service is not restricted to CalTrain passengers, 96 percent of respondents connect with the train.
- Eighty-nine percent ride the shuttle both morning and afternoon. Of the 11 percent who do not, 79 percent still take CalTrain in the other direction, but they use other means to get to the station, chiefly walking or getting a ride.
- Sixty-seven percent use the service 5 days per week. This is an increase over the year-ago level of 59 percent and is about the same percentage as CalTrain riders in general.
- Sixty-five percent buy a monthly train pass, up from 60 percent in the previous survey. Another 16 percent buy tickets good for more than a single round trip.
- Sixty-one percent of those who worked at their present location before the shuttles started never, or hardly ever, used CalTrain then. Another 8 percent used the train fewer than 3 days per week. This is mainly because convenient connections between stations and workplaces did not exist.
- Sixty-seven percent had a car available to them on the day of the survey but chose to take the train and shuttle instead. This percentage is similar to train riders in general.
- Sixty-three percent are male, a percentage similar to train riders with work destinations outside the San Francisco central business district.
- The median age is approximately 34.
- Sixty-five percent have at least a 4-year college degree; 24 percent have a graduate degree.

FUNDING

Figure 5 indicates that the initial state share of 67 percent of funding declined to 25 percent in fiscal year 1990–1991. The combined city and private share increased to 50 percent, and the transit districts made up the remaining 25 percent, sharing costs with the state on the same basis as they do the CalTrain service. The state share has declined both because the original demonstration grant funds are exhausted and because current state policy is that mass transit services should be funded locally.

Caltrans does not collect funds directly from the private sector. Instead, the agency signs cooperative agreements with cities in which the cities pledge to provide a specified sum, which currently amounts to 50 percent of the shuttles' contract cost. Cities then recoup as much from private interests as they can. The percentage of the combined city/private share paid by the private sector has varied by city in the first 2 years of the program, ranging from 18 to 67 percent and averaging 48

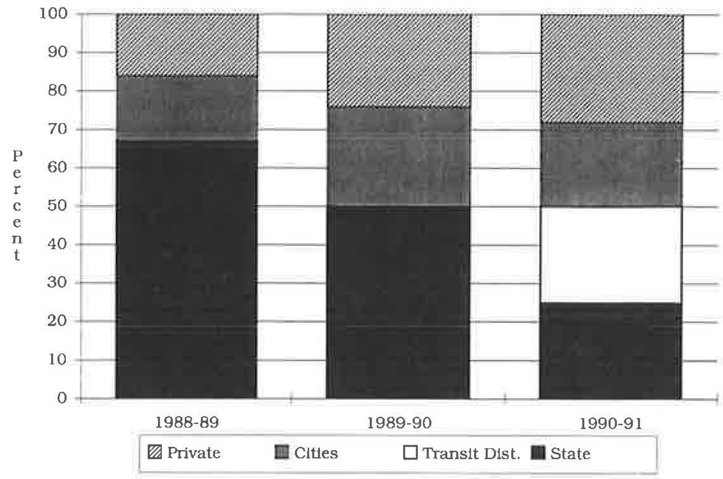

FIGURE 5 CalTrain Shuttle funding.

percent. In fiscal year 1990–1991, two of four cities will obtain more from employers and developers, which will result in an average private share of 56 percent, or 28 percent of all shuttle funding.

Companies volunteer to contribute, sometimes on the basis of amounts suggested by cities or developers. No city ordinance requiring corporate participation has yet been passed. Typical annual contributions for companies with less than 1,000 shuttle-served employees are $1,000 to $2,500. On the Cupertino route, two large computer businesses, each with 2,500 to 5,000 served employees, now contribute $8,855 per firm, or one-third each of the combined city/private share (they had previously split their cost responsibility according to the number of employees at each company). Cupertino, whose city manager took a lead role in getting the companies to give so much, pays the remaining one-third.

FARE REVENUE

Shuttle riders pay no fare, so no revenue is generated directly. However, new train revenue is produced, and the passenger survey summarized earlier allows it to be measured. Revenue from those who used the train before the shuttle started is subtracted, except for any additional travel. Revenue from riders whose companies moved to the area after shuttle service started is partially counted.

On the basis of these formulas, in May 1990 new train revenue amounted to 26 percent of the cost of shuttle operation for the four original routes, up from 16 percent a year earlier, and 20 percent of the cost of all routes, including the new Menlo Park services. Marginal train costs were almost nothing.

OTHER SUBURBAN WORKPLACE SHUTTLES SERVING CALTRAIN

The Caltrans-managed shuttle services discussed in this paper are only one type of transit link between train stations and workplaces in San Mateo and Santa Clara counties. (Because San Francisco and downtown San Jose are traditional central cities, connecting services there are beyond the report's scope.)

The Santa Clara County Transit District operates full-size buses on four dedicated train connection routes serving the heart of Silicon Valley employment, the Golden Triangle. Each route meets about six morning and seven evening trains in the primary commute direction and carries between 25 and 42 transferring passengers each morning. Another five Santa Clara County Transit routes carry between 26 and 101 morning transfers each, but they are not train-dedicated services. Passengers with monthly or weekly train tickets ride County Transit free when traveling away from trains. Alternatively, for $18/month, passengers may purchase a "Peninsula Pass" sticker affixed to the monthly CalTrain ticket, which permits unlimited travel on all County Transit lines and those of neighboring counties.

The next most important link between CalTrain and suburban workplaces is the Marguerite, a small-vehicle service contracted by and serving Stanford University. Each morning, about 135 passengers transfer from the train to the Marguerite. Vehicles are high-roof van conversions with about 15 perimeter seats and considerable standing room.

At least four employers and three land developers operate their own shuttles to CalTrain stations in San Mateo and Santa Clara counties. High-roof van conversions are most commonly used, although two companies operate low-roof vans. Some firms contract for service, whereas others own or lease vehicles and provide their own drivers. A business park that leases prefers this to outright ownership because maintenance is covered. But another company, which bought a vehicle, is satisfied that major maintenance is covered under an extended warranty. Driver wage costs are a minor or nonexistent issue if drivers can perform other work the rest of the day, as is the case at one company that uses employees who were already on the payroll.

Most private shuttles make several trips to and from the station each peak period. Of five operations studied, the average number of daily morning transfers is 20. Some companies charge users a nominal amount, whereas others provide free service. One firm that formerly assessed its employees $10 per month dropped the fee: it was not covering the cost of shuttle operation, and the shuttle was not that expensive anyway.

Companies offer several reasons for initiating and fully funding their own shuttles. The two most common may be to retain employees after a corporate move by offering an alternative to driving long distances and, among developers, to make remote office leasing easier. A third reason is likely to become more important: shuttles are a way to satisfy government requirements to reduce solo driving and clean the air.

SUBURBAN WORKPLACE SHUTTLES SERVING OTHER COMMUTER RAILROADS

There are other U.S. locations where public agencies are at least somewhat involved in funding or managing shuttle services between suburban commuter rail stations and nearby employment clusters. The following are a few examples. Wholly private operations are not discussed.

Near Princeton, New Jersey, a transportation management association (TMA) contracts with a local limousine company to provide two small vehicles with drivers for peak service between a New Jersey Transit station and the Princeton Forrestal office complex located about 5 mi away. Started with an Urban Mass Transportation Administration entrepreneurial services grant, the service is now supported entirely by the developer of the complex and three employers there. TMA funding comes partly from the same four firms and partly from the New Jersey Department of Transportation. Six morning trips and five evening trips are operated, connecting with both New York and Philadelphia trains. The shuttle is free to employees of sponsoring firms.

In suburban Philadelphia, the Southeastern Pennsylvania Transportation Authority (SEPTA) operates its own full-size buses between commuter rail stations and major employers (including a shopping mall) on five routes as of mid-1990. Many routes operate all day. These services are fully funded by businesses that requested that SEPTA operate them. Many firms were having difficulty recruiting inner-city employees. Buses are timed to meet SEPTA's commuter trains, and bus timetables showing connections are readily available at key train stations. Passengers ride free by showing a rail pass.

In suburban Chicago, the Pace public bus district contracts with private operators to run home-oriented shuttles to and from selected Metra commuter rail stations. Some vehicles carry passengers between stations and workplaces on return trips, but not many commuters took advantage of the work link as of mid-1990.

A major work-end shuttle network is essential to development of the Los Angeles–Orange County commuter rail corridor, according to Orange County Transportation Commission members quoted in the September 25, 1990, *Los Angeles Times*. Like the San Francisco–San Jose corridor, this one has substantial employment clusters along at least 40 mi of its 58-mi length, but businesses are usually beyond easy walking distance.

SUMMARY AND OUTLOOK

The 1989 *CalTrain Passenger Survey* indicated that 12 percent of train passengers going to work in San Mateo and Santa Clara counties completed their trips on small vehicle shuttles, whereas another 17 percent rode full-size buses operated by transit districts on regular routes (some dedicated to meeting trains, some not). In the year since, the proportion of small-vehicle users has probably grown.

The CalTrain shuttle program has demonstrated that reliable, swift, and dedicated connectors between train stations and workplaces can attract passengers who have the option of driving. Ridership growth has been strong since the October 1989 earthquake, despite the major handicaps of free workplace parking and dispersed employee trip patterns.

Employers and developers now contribute a greater percentage of the cost than initially. Public sources include the state, the three San Francisco Peninsula transit districts, and individual cities served. An increased private role appears appropriate, but the involvement of several public agencies and the extra staff needed for an expanded program are likely to make service additions more difficult.

Therefore, alternatives such as partial public subsidy of company-managed shuttles are under study. As discussed earlier, several employers already run their own train shuttles, and workers at other firms are pressuring their companies to do so, particularly because affordable housing is so far away.

In California's principal urban areas, the future looks bright for rail-based workplace shuttle services. Voters have funded an ambitious program of rail improvements, but it may be some time before major office developments are located within walking distance of a large number of train stations. Until then, small vehicles able to negotiate company parking lots will be needed to make the train system accessible.

ACKNOWLEDGMENTS

The author is grateful to the California Department of Transportation; the California legislature; the cities of Cupertino, Menlo Park, Mountain View, Redwood City, and San Carlos; Redwood Shores Properties; and many San Francisco Peninsula employers for providing CalTrain Shuttle financial support. Since July 1, 1990, San Francisco, San Francisco County, the San Mateo County Transit District, and the Santa Clara County Transit District have also supported the service.

The following persons were kind enough to provide information on their shuttle services in the San Francisco Peninsula: George Denise, Oyster Point Business Park; Linda Edwards, Gateway Office Park; Georgina Lehne, GTE Corporation; Martha Mires, Hewlett-Packard; and Dick Schaublin, Hitachi America. Dick Brazda, Pace Suburban Bus, Chicago; Harry Garforth, SEPTA Commuter Rail, Philadelphia; and Nancy Podeswa, Princeton Forrestal TMA, Princeton, New Jersey, provided information on their shuttle services. They are not responsible for factual errors.

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GO Rail 1989 Survey Results

JULIUS GORYS, MURRAY MCLEOD, AND FRANK WILLIAMS

The Government of Ontario (GO) commuter rail system provides an attractive alternative to automotive journey-to-work travel in the greater Toronto area. Operating with conventional rail technology, the 7-line, 47-station system carries more than 80,000 passengers each weekday, or some 20 million passengers per year, over its 356-km network. The system is in a continuous state of expansion and upgrade to meet the demands of Toronto-bound commuters. Systemwide surveys of riders have been conducted as a cooperative effort between GO Transit and the Ontario Ministry of Transportation since 1981. The biennial surveys collect both origin-to-destination and rider-characteristic data, which provide a base for operational and policy-planning purposes. Some results of the 1989 survey are described.

Government of Ontario (GO) Rail is the first interregional transit system in Canada created and funded by a provincial government. The original GO Rail began as a demonstration project in 1967 with the premise that, by attracting motorists off the highways, such a service would reduce the need for new multimillion-dollar expressways. The system has since been expanded to seven lines that serve an area of more than 8000 km^2 (3,000 mi^2) with a population of more than 4 million. Figure 1 shows the lines and stations in 1989.

In addition to rail service, GO Transit operates bus services in support of and independent of the rail system. Of the 10 million passengers who use the GO Bus service annually, approximately 10 percent use routes connecting with rail services.

The original Lakeshore lines operate on all-day, two-way schedules over most of their routes. The Lakeshore West route operates at full service (10 min peak, 60 min off-peak) for only about two-thirds of its length, with a limited three-train extension in the peak direction for the remainder. The newer routes operate between one and five trains daily in the peak direction over a 2-hr period.

Free parking is provided for more than 20,000 vehicles on the system, but despite the large number of spaces, demand at many of the lots often exceeds supply. To dissuade riders from parking at the stations, kiss-and-ride lanes for passenger pickup and drop-off are provided at most stations. In addition, special access loops for buses and integrated fare arrangements with most local transit operators are now in place. Despite these efforts, parking lot capacities continue to be a major problem for GO Transit.

GO fares, charged by distance over a zone system, are much less than the cost of commuting by car but do not undercut the prices set by local transit operators. The goal set for GO Transit is to recover 65 percent of operating costs through fare box revenue with the provincial government making up the balance and paying all capital costs.

Ontario Ministry of Transportation, 1201 Wilson Avenue, 3rd Floor, West Tower, Downsview, Ontario, Canada M3M 1J8.

Union Station in downtown Toronto is the hub of the GO Rail system and is directly linked to the Toronto Transit Commission's (TTC's) extensive subway and surface transit network. Of the 80,000 daily rail passengers, 98 percent exit or board GO Rail at Union Station, and nearly one-third of these passengers transfer to TTC services. To promote the use of both transit systems and to make this transfer more economical, a combined GO/TTC monthly pass package known as Twin Pass was introduced in January 1988. An average GO monthly pass costs about $115, and a TTC monthly pass is $53. The Twin Pass offers this combination at a $20 discount. Acceptance of this fare package has been high; more than 10 percent of GO riders purchase it on a regular basis.

Future demand on the GO Rail system will come from all areas of the greater Toronto area (GTA). Downtown Toronto is expected to continue to dominate employment activity in the GTA. To date, GO Rail service has expanded incrementally in response to emerging trends in population and employment growth. The period from 1987 to 1989 was characterized by sustained economic expansion, which has, however, slowed in recent months. The Ontario Ministry of Transportation (MTO) predicts that current ridership levels will more than double during the next 30 years, and it is anticipated that all seven lines will be upgraded to full-service status during this time period. Extensions of the existing rail lines and upgrades of some limited services had been completed by early 1990, and plans have been made for additions to the system.

SURVEY METHOD

Given the high growth experienced by GO Rail, an ongoing survey program has proved useful in measuring the various changes on the system. GO Transit is responsible for distribution and collection of the survey forms, and the Transportation Demand Research Office of MTO administers the data collection, processing, and report generation. In 1989 the consulting firm of Cole, Sherman and Associates was contracted by MTO to assemble the data base and prepare a report. GO Transit and MTO share the responsibility for design and development of the survey content.

Table 1 gives data collected by each of the GO Rail surveys undertaken since 1981. Changes between the 1989 and previous surveys include the addition of questions concerning duration of residence, previous trip method, fare type following the introduction of the new Twin Pass program, and parking at GO Rail stations. Because of space limitations, questions pertaining to trip purpose and family income group, which had not changed significantly in other years, were dropped from the latest version. They may be reinstated in future surveys to maintain a time series data bank.

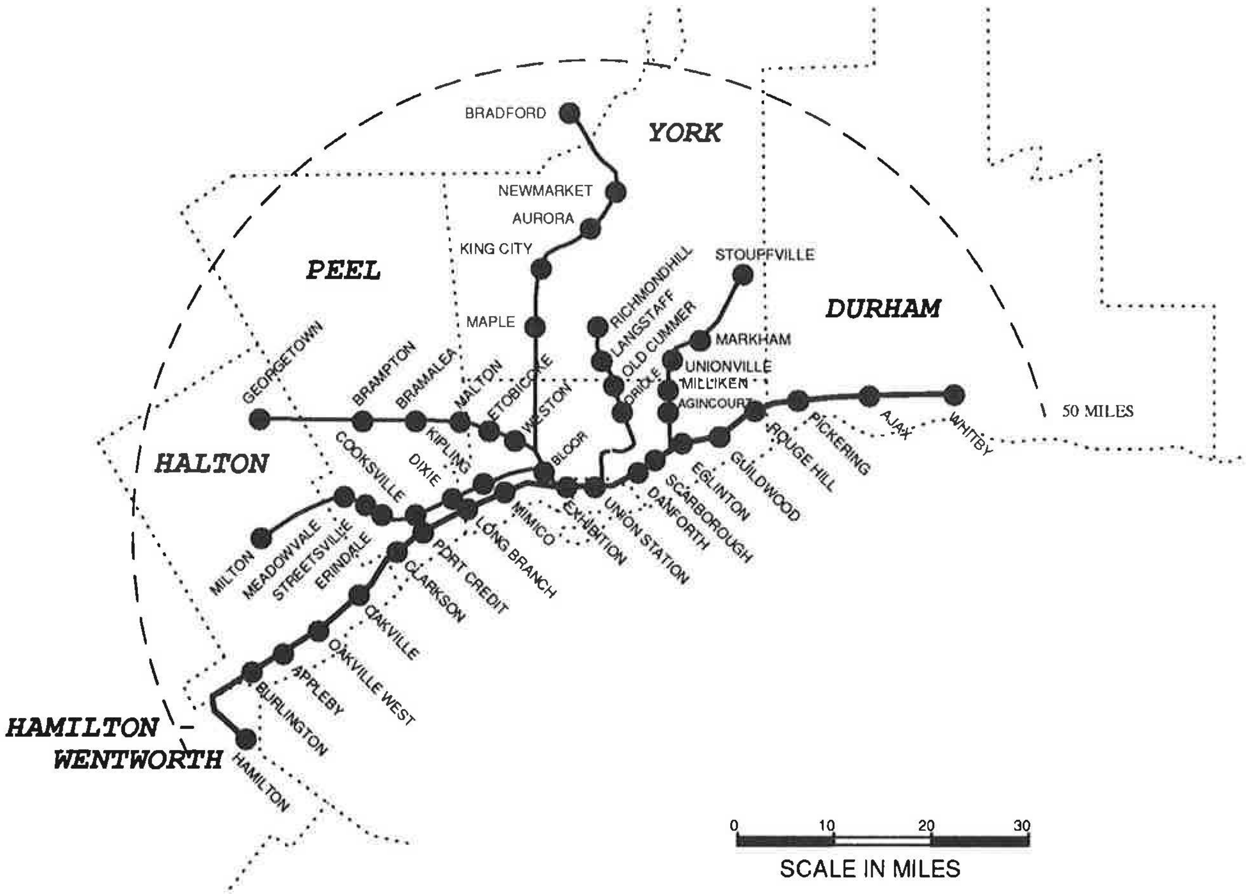

FIGURE 1 GO Rail system lines and stations, 1989.

TABLE 1 DATA COLLECTED IN GO RAIL SURVEYS

		81	83	85	87	89
Origin End:	Trip Origin	*	*	*	*	*
	Origin Purpose	*	*	*	*	
	Boarding Station	*	*	*	*	*
	Boarding Time	*	*	*	*	*
	Mode Station	*	*	*	*	*
Destination End:	Trip Destination	*	*	*	*	*
	Destination Purpose	*	*	*	*	
	Destination Station	*	*	*	*	*
	Mode from Destination	*	*	*	*	*
GO Fare:	Fare Medium	*	*	*	*	*
	Reason for Single Fare Use		*	*		
	Fare Category (e.g. student)	*	*	*		
Twin Pass Users:	Previous Fare Medium					*
	Uses Twin Pass for GO Bus					*
New User:	Previous Trip Mode					*
GO Frequency:	Trips/Week	*	*	*	*	*
TTC Use:	Trips/Week				*	*
	TTC Fare Medium				*	*
Reverse Trip:	On Same Day	*	*	*	*	
	Mode Used	*	*	*	*	
Socio/Economic:	Male/Female			*	*	*
	Age			*	*	*
	Family Income	*	*	*	*	
	Car Availability for Trip	*	*	*		
	Why GO Used Over Auto	*				*
GO Use History:	Years of Use	*	*	*	*	*
Residence History:	Years at Present Residence	*	*	*		*
	Location of Previous Residence	*	*	*		
	Importance of GO Transit					*
Employment History:	Years at Employment Location	*	*	*		
	Location of Previous Employment	*	*			
Drive & Park Users:	If Parking Lot Closed, How Would Make This Trip					*

GO Rail surveys are conducted on a single midweek day in November to minimize the effects of special events, vacations, and compressed workweeks. The day of the survey is chosen to correspond to GO Transit's own count program, which provides calibration data. Survey cards are distributed as riders board at Union and other Toronto stations for all afternoon outbound trains. This has proved to be a better approach than distributing forms at all 47 GO stations to collect inbound trip information. More than 80 percent of the daily outbound trips on the rail system are surveyed with this method. Boxes were provided at each station to collect completed responses. A small number of surveys were mailed back, although no postage was provided.

In the 1989 survey, 17,600 valid responses were collected, a response rate of 42 percent. Although more responses were collected for the 1989 survey than in previous years, the response rate was slightly lower.

Trip records on survey cards were geocoded using the Universal Transverse Mercator 6-degree coordinate system. Four points on each survey card were assigned a geocode: origin, access station, egress station, and final destination. Each point was assigned an *x-y* coordinate, which allows better analysis of characteristics such as distance between points of an individual's trip. Geocoding also provides more flexibility for geographic analysis, because each set of coordinates can be aggregated to any zone system.

Survey records were expanded to daily totals by using GO Transit's count data, which record boardings and alightings for each station by train number. Expansion factors were then calculated for each egress station, which, when summed, equal the daily outbound ridership.

ISSUES

Current GO Rail survey data are necessary to understand the forces affecting the system in recent years. As indicated in Figure 2, ridership on GO Rail has increased by 20 percent per year during the study period. Traditional forecast methods were unable to explain this accelerated growth. Several questions on the survey were designed to give planners insight into the characteristics of new GO riders.

A portion of the growth can be attributed to increases in service levels on some of the rail lines. During the study period, two of the limited-service lines were upgraded by the addition of one or two trains in the peak period. An analysis of the geocoded trip segments for the 1987 and 1989 surveys enables planners to identify changing trip patterns resulting from service improvements.

The combination of rapid growth in demand and new services raises a number of operational concerns for GO Transit. By analyzing trip patterns and new demand characteristics, the operator is able to rationalize parallel and complementary bus services, plan station size and parking requirements, and add extra cars to existing consists to meet the higher demand.

A fourth major issue that can be addressed through analysis of survey data concerns travel demand research. Insight into trip generation, transit mode split, fare elasticities, and sensitivity to increased service levels can be gained from the survey data.

SURVEY RESULTS

Though rail ridership has increased rapidly during the study period, GO Bus ridership has increased only moderately, actually dropping during the past year (see Figure 2). Much of the decline in bus ridership can be attributed to a two-station extension of the Lakeshore East GO Rail line, which replaced a bus service. Congestion on the approaches to Toronto has increased travel times by road and inhibits the use of the GO Bus system. There appears to be little shift from GO Bus to GO Rail in most other corridors; only 1.6 percent of new riders indicate GO Bus as their previous travel mode. The largest segment of new riders on the rail system indicated that they did not make the trip at all before their use of GO Rail. Nearly 50 percent of new riders indicated that they did not previously make the surveyed trip.

Figure 3 shows growth and current ridership levels for each GO Rail line between 1981 and 1989. The full-service Lakeshore lines, which together account for 70 percent of total ridership, dominate the picture. GO Transit initiated limited service on the Milton, Bradford, and Stouffville corridors after 1981.

Growth was evident on all lines between 1981 and 1987. The largest increases in ridership were on the new Milton and both Lakeshore lines. The sustained Lakeshore West growth during a time of increased competition from the new Milton service is of particular interest. More than 80 percent of ridership growth was concentrated on these same three lines during the survey period. Most of the growth on Lakeshore East and Milton can be attributed to either extensions of the line or added service. The rate of growth on the Lakeshore West line, however, continued to exceed forecasts. Analysis of data

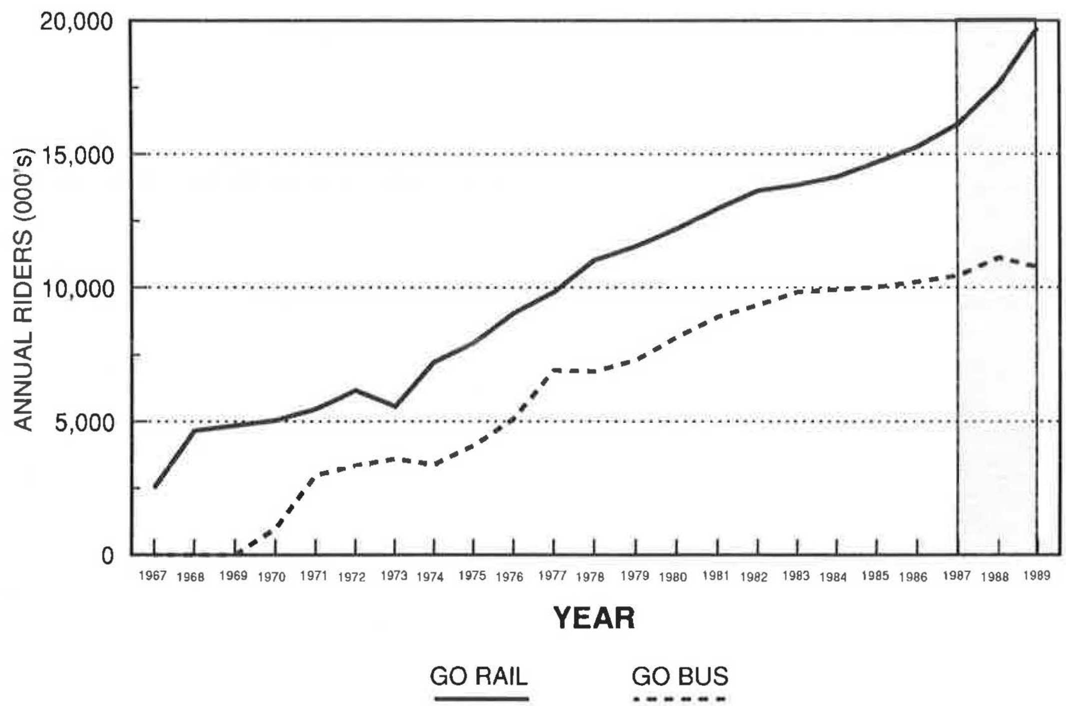

FIGURE 2 GO system annual ridership.

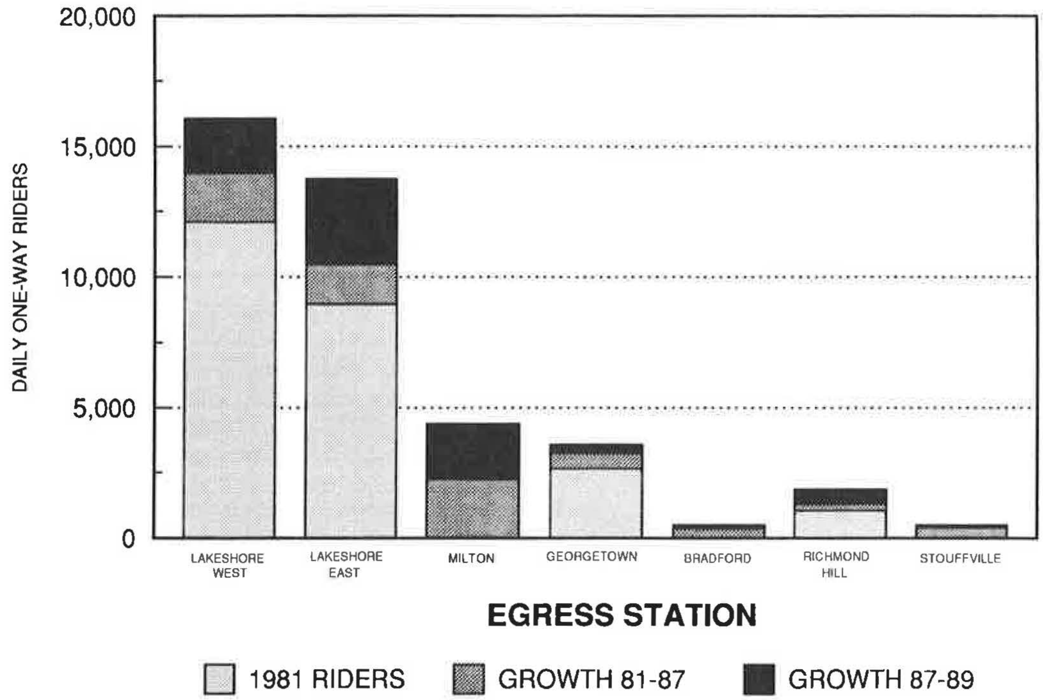

FIGURE 3 Ridership growth by line, 1981–1989.

collected by the 1989 GO Rail Survey permits a more detailed study of the forces influencing ridership growth in this corridor.

Figure 4 shows growth in patronage at individual stations along the Lakeshore West GO line. The chart shows the effect of the full-service portion of the line. Oakville is the current terminus for all-day service and has both the highest passenger volumes and egress trip lengths, because GO patrons from areas further to the west travel there to take advantage of greater flexibility in travel times. Between 1987 and 1989, however, Oakville experienced little ridership growth compared with the two stations immediately to its east.

This trend is interesting because these areas of GO growth are fully developed residentially, and GO Rail market pen-

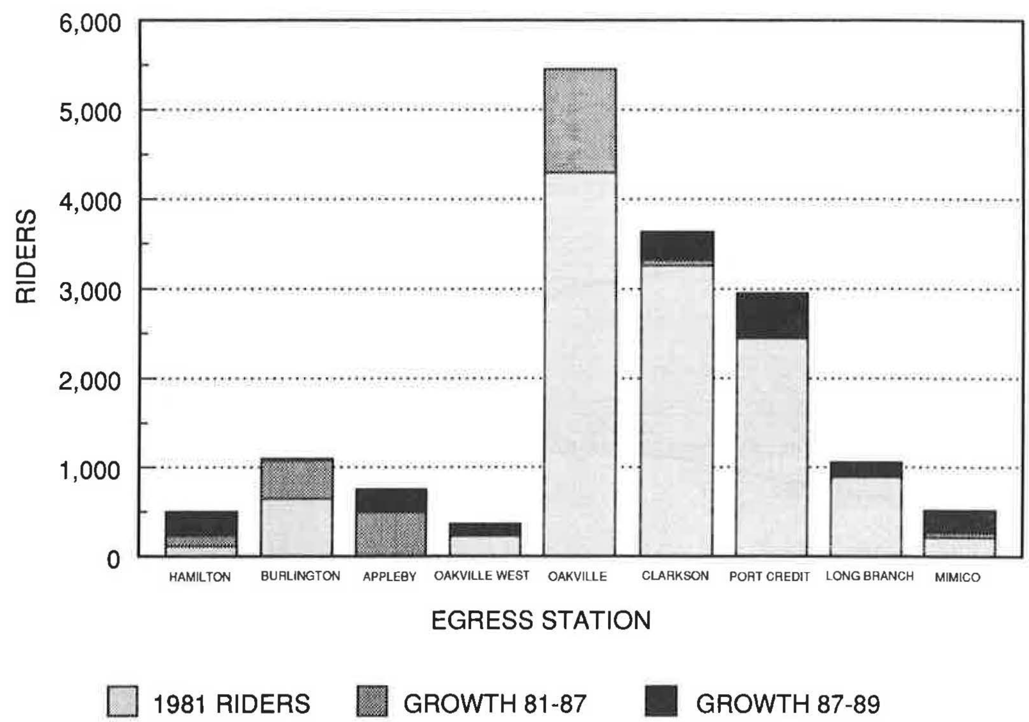

FIGURE 4 Growth in patronage at stations on Lakeshore West line, 1981–1989.

etration was assumed to have matured. Figure 5, which shows previous trip method by years at residence for all riders at the Clarkson station who indicated that they had been riding the GO service for less than 1 year, was extracted from the survey data to examine this question. The central feature is the large number of new residents–new riders who did not previously make this type of trip, which indicates both a higher rate of residential turnover and greater attractiveness of GO service than is suggested by the forecasting model. More than 90 percent of riders indicated that the availability of GO Transit service was very or somewhat important to their choice of residential location (see Figure 6). Mode shift, particularly from automobile, suggests another factor that probably influences ridership. The number of respondents indicating automobile as a previous trip mode rises as length of time at current residence increases. This may indicate dissatisfaction with growing congestion.

Congestion on the road system feeding Toronto has become increasingly significant in recent years. Total trips across the metropolitan border in the peak period (3 hr) have increased by 12 percent since 1987. GO Rail carried 9 percent of all trips and 20 percent of the increase in trips over the border in the peak period. Current cordon counts indicate that GO Rail has carried more than 100 percent of the increase in trips to the primary GO Rail market in downtown Toronto since 1987.

Besides investigating growth of ridership on the GO system, the 1989 survey collected information that can be used to evaluate other aspects of GO service. Table 2 compares fare media choices by riders in 1989 with those in 1987. The two dominant fare types continue to be Monthly Pass and Ten Ride tickets, which offer discounts of 10 to 20 percent from the cost of a single fare. The small percentages counted in the Single and Other fare categories reflect the low proportion of occasional riders in the average weekday total. As hoped, introduction of the Twin Pass resulted in a shift to monthly pass use. Purchases of the Twin Pass have been consistent with forecasts provided by transportation planners. A series

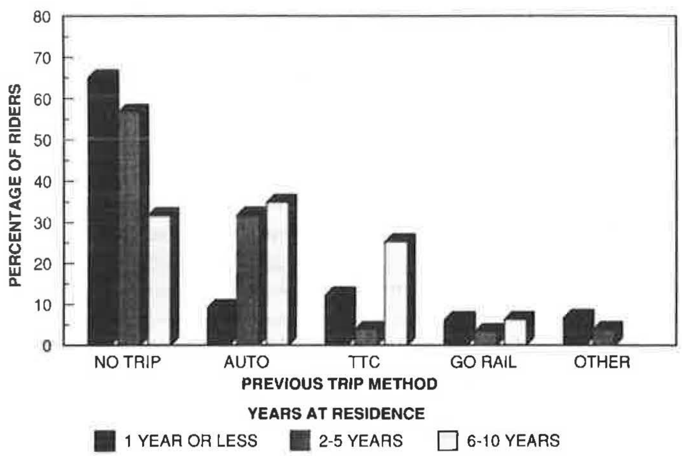

FIGURE 5 Previous trip method by years at residence, new Clarkson riders.

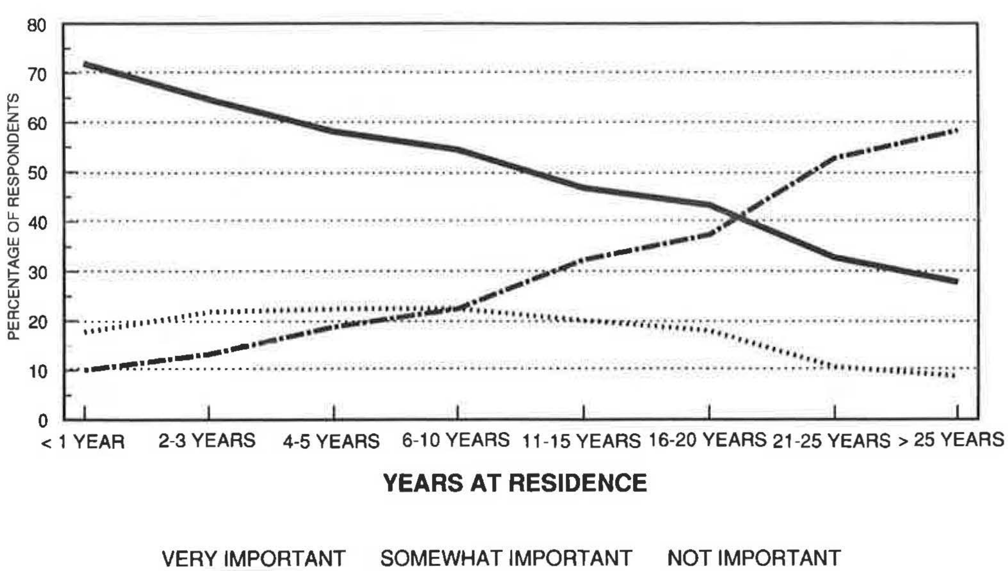

FIGURE 6 Importance of GO to choice of residence.

TABLE 2 FARE MEDIA CHOICES BY RIDERS, 1987 AND 1989

	% 1987	% 1989
MONTHLY PASS	43.2	36.8
TWIN PASS	-	10.3
(TOTAL GO PASS)	(43.2)	(47.1)
TEN RIDE TICKETS	46.6	43.2
SINGLE FARE	9.7	8.1
OTHER	.4	1.2

TABLE 3 GO AND TTC TRIPS TAKEN DURING LAST 7 DAYS

NUMBER OF TRIPS	% ON GO 1987	% ON GO 1989	% ON TTC 1987	% ON TTC 1989
0	0	0	47.7	47.7
1 - 5	10.3	9.6	23.1	20.3
6 -10	77.8	77.7	22.2	21.5
11-15	11.5	12.1	5.0	6.0
16 PLUS	.4	.4	1.9	1.2

TABLE 4 EGRESS MODE, 1987 AND 1989

EGRESS MODE	% 1987	% 1989
WALK	12.1	11.6
LOCAL BUS	16.4	15.2
GO BUS	4.2	1.7
DRIVE AND PARK	51.7	56.2
RIDE IN CAR	2.1	3.6
KISS 'N RIDE	12.6	8.5
OTHER	.9	3.2

of fare elasticities, which relied heavily on previous GO system surveys, was developed as necessary input to cost-benefit negotiations between GO and TTC.

Figure 7 shows access mode by distance to Union Station for 1987 and 1989 for the two major modes. Walk and transit combined account for 97 percent of all trips to Union Station, although fewer than one-third of GO riders transfer to the subway on any given day. The chart clearly shows the 1.5-km (approximately 1-mi) break point between walk and transit. The introduction of the Twin Pass was expected to influence this relationship, but only a slight shift in mode by distance has occurred.

In addition to affecting access mode and distance, the Twin Pass program was expected to influence the number of trips made on transit. Table 3 gives the number of GO and TTC trips made by riders during a 7-day period using various fare media. The table indicates little difference from 1987 for all GO riders, but it is necessary to consider that segment of the market purchasing the Twin Pass. Twin Pass users have increased their trip making on the TTC portion of the system. Nearly 35 percent reported that they made more than 10 TTC trips over a 7-day period, compared with 8.4 percent for all other fare types.

At the destination, which is in most cases the home end of the GO Rail trip, automobile is by far the preferred egress mode. Table 4 gives percentages by egress mode for 1987 and 1989. Because average egress trip length on the system is approximately 4 km and integrated local transit connections are available at nearly all stations, it is somewhat surprising that use of the automobile continues to grow. Free parking at all stations has no doubt contributed to this trend but, on the other hand, has been a major selling point in attracting commuters from their cars to GO for the major portion of their trip. As discussed earlier, riders have come to expect the availability of free parking, to the point where overall ridership on the system appears to be affected. The decline in Go Bus as an egress mode is attributable to replacement of some services by train extensions, but the deterioration in the share of GO riders using local transit is of more concern.

To explore the relationship between parking and GO ridership, respondents who parked their cars at the station were asked how they would access the GO system if their usual parking lot was closed temporarily for resurfacing. Clearly, the provision of parking is a significant factor; more than 30

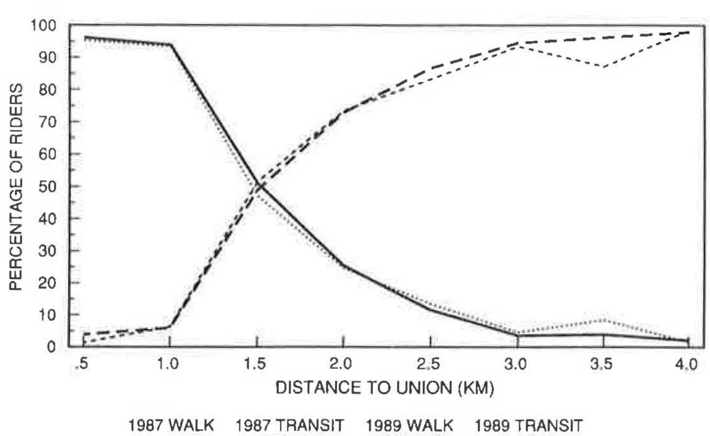

FIGURE 7 Access mode by distance to Union Station.

percent of respondents indicated that they would not use the GO system at all for their trip without it (see Table 5). Interestingly, use of carpools and local transit are poorly perceived as trip-making options, though they are probably valued by transportation planners as the best solutions to parking and congestion problems at and around the stations.

Survey respondents were provided a list and asked to rank their top three reasons for using GO Rail. Table 6 gives only the top-ranked reasons for using GO.

Riders recognize the increasingly prohibitive travel time and cost of driving to and parking in the core area. The low captive market for GO reflects the suburban nature of the service; car ownership is more necessary. Previous GO surveys have also indicated a higher-than-average family income for the typical GO rider compared with other transit users.

Although a comments area was provided on all previous GO surveys, 1989 was the first time that rider comments were grouped, coded, and analyzed. Overall, 55 percent of riders provided a codable comment. The split into positive, negative, and suggestion categories was approximately one-third for each. Table 7 gives the specific comment groupings available for analysis in the 1989 survey. On the positive side, the service-related and general complimentary comment types dominated, with 90 percent of the total. Individual preferences and personal schedule requirements are evidenced by the high negative ranking for the service category. Perhaps the most interesting feature of Table 7 is the negative comments directed toward fares and pay parking. The low negative ranking for GO fares indicates that cost may not be a major issue for most riders. The number of GO parking lot complaints reinforces the concerns riders have about this aspect of the system.

The number of riders expressing concern about the possible introduction of some form of pay parking, even though no pay parking program exists, is of particular significance. Stratified analysis of the coded comments indicated no significant differences between geographic areas, new and old riders, or regular versus irregular riders.

TABLE 5 TRAVEL OPTIONS TO GO STATION IF PARKING LOT CLOSED

TRAVEL OPTIONS TO STATION	%
DRIVE TO ANOTHER STATION	27.5
WOULD USE KISS'N RIDE	22.5
DRIVE TO FINAL DESTINATION	7.5
TRANSIT TO FINAL DESTINATION	21.0
GO BUS TO DESTINATION	4.5
CARPOOL TO FINAL DESTINATION	2.5
USE LOCAL TRANSIT TO STATION	5.0
OTHER	9.5

TABLE 6 TOP-RANKED REASON FOR USING GO

REASON FOR USING GO	%
COST	23.4
RELAXING	20.7
FAST	16.9
CONVENIENT	13.8
NO OTHER MODE	10.5
DIRECT SERVICE	9.2
SAFE	2.9
RELIABLE	2.6

TABLE 7 COMMENTS BY RIDERS

COMMENT GROUP	% POSITIVE	% NEGATIVE
SERVICE	50.1	61.3
PARKING LOTS	2.9	15.0
SERVICE ENVIRONMENT	4.5	9.8
FARES	2.1	7.8
PAY PARKING	0	1.2
GENERAL	40.0	4.9

SUMMARY

The GO Rail system is an integral component of the GTA transportation system. During the past decade, and in particular during the past 2 years, GO Rail has experienced strong sustained growth in ridership, which has enhanced its role in facilitating both cross-boundary and GTA travel. Current and time series data are required to ensure that future priorities are well placed. Systemwide snapshots of rider and trip-making characteristics on the GO Rail system, such as the 1989 GO Rail Survey, have proved to be a valuable source of operational and policy planning data. Analysis of the 1989 survey reflects the type of study that has been completed to date and demonstrates the flexibility of the data base to respond in a timely manner to topical issues.

ACKNOWLEDGMENTS

The authors wish to acknowledge the efforts of the following persons, whose participation in either the 1989 GO Rail Survey or the preparation of this report were invaluable: R. Boyle, G. Johnston, and D. K. St. Clair, GO Transit; J. Terry, Cole, Sherman and Associates, Ltd.; J. Tao, MultiSystem Consultants; D. S. Thompson, MTO; and the staff of the Transportation Demand Research Office of MTO.

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Evaluation of Training Programs in Rail Transit: Its Role and Status

NAOMI G. ROTTER AND CLAIRE E. MCKNIGHT

The role and status of training evaluation in rail transit are reviewed. Three forms of evaluation—process, outcome, and utility—are considered. Training evaluation in a sample of commuter rail agencies is then examined. Findings indicate that reaction forms are ubiquitous. One rail agency is attempting to link training evaluation to performance appraisal for its nonunion employees. The most sophisticated use of evaluation was found in a large freight railroad. Barriers to the conduct of more thorough evaluations are the lack of training staff, nonexistent or outdated performance standards, and a perception that evaluation is a tool to justify decisions already made. Needs and job analyses are recommended for reducing the barriers. Techniques of training evaluation that could be used in the rail industry are described. Evaluation can be done at the employee, program, and organization levels. Evaluation is also discussed as it relates to management strategy. Advantages include its facilitating detailed feedback to management, its use for changing training, and its capacity to build commitment to training among managers. The relative benefits and drawbacks of educational technologies are considered.

A 1982 report (*1*) indicated that organizations in the United States were spending more than $130 billion annually for training. Adjustment for inflation would set the figure today at more than $170 billion. Such a remarkable expenditure reflects the cost of maintaining a work force that is up-to-date in its knowledge and skills. The question remains, Is the money well spent?

Technical training programs are generally initiated to enhance employee performance. Whether they meet this goal can only be ascertained through systematic evaluation. Considering the amounts spent on training, it is surprising that a review of programs in both the public and private sectors (*2*) indicates that little is known about the results of training.

SCOPE AND FUNCTION OF TRAINING

The rail industry devotes a substantial amount of money to training at both the technical and managerial level (e.g., a major U.S. rail carrier reported a budget of $4.6 million for technical training alone). However, a recent study (McKnight and Rotter, unpublished data) of commuter rail agencies in the New York–New Jersey metropolitan region indicated that several job categories still use on-the-job training that is unsystematic, fragmented, and unsupervised. To the extent that rail agencies rely on such hit-or-miss tactics in their training, employees cannot be expected to acquire the understanding, job skills, and work attitudes that make for a productive work force. Systematic training becomes all the more important as jobs in the rail industry become more complex, with the increasing use of electronic and computerized controls in equipment.

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ROLE OF EVALUATION

Evaluation of training to assess its effectiveness and efficiency is critical. Effectiveness considers improvement in employee skill level, improvement of the training program, and feedback to managers, participants, and training professionals (*3*). Efficiency assesses cost-benefit ratios, which are derived by comparing the dollar value of improved job performance resulting from training with the costs of training.

Assessment of the effectiveness of training can disclose deficiencies that detract from its ability to achieve successful outcomes. Examples of deficiencies include inaccurate needs assessment, inappropriate selection of trainees, ineffective delivery of the programs, and inability or lack of opportunity to transfer acquired skills to the workplace (*4*). An assessment of the utility of the training program to the organization informs management of the strategic value of training. By attaching a dollar value to training, management permits training to be factored into longer-range plans for achieving organizational success.

Another benefit is that of conveying a message to management, other divisions, and the trainees that training is to be taken seriously (*5*). For example, the technical training unit of a large freight railroad demonstrated decreased costs through a fuel reduction training program. Consequently, upper management was convinced of training's value and moved the unit from a staff to a line division (McKnight and Rotter, unpublished data).

TYPES OF EVALUATION

Comprehensive training evaluation incorporates assessment of both the process and the impact of training. Regardless of the type of evaluation, the evaluation process requires two activities: setting standards or criteria for measuring success and determining the extent to which the training contributes to achieving that standard (*6*).

Process Evaluation

The initial phase of evaluation focuses on issues such as identification of the type of training that would be most useful in ameliorating the problem and the group that should receive the training, whether the training is reaching that group, whether the course is adequately designed, and whether the training is being delivered as planned.

One particularly useful technique at this stage is content evaluation (*7*). The first step requires that job elements (required knowledge, skills, and abilities) be identified through job analysis. Typically, subject-matter experts evaluate the extent to which the training course contents reflect the job or skill domain. As an example, the previously mentioned freight railroad, when designing a welding course, had it evaluated both by operating departments and by experts in welding.

Such evaluations help ensure that the course is job related. Results can demonstrate either training deficiencies or training excesses. Deficiencies result when high-priority training needs are omitted from the training program; excesses reflect unwarranted emphasis relative to the training need. Both require refinement of the course.

Process evaluation includes program monitoring to determine which group needs the training and follows through to see that the group in fact receives the training. The first objective requires employee diagnosis. This can be accomplished through employee testing, performance appraisal, or supervisory observation. The second objective requires goals for supervisors that tie their evaluations to their effectiveness in getting the requisite training for their employees.

Outcome Evaluation

The second phase of evaluation assesses the impact of training. This aspect of evaluation seeks to determine whether learning took place. Do the trainees know more at the end of training than they did at the beginning? Another critical aspect of evaluation deals with changes in behavior. Is the newly acquired knowledge or skill used on the job?

The issues of learning and change in job behavior suggest the need to evaluate at various times during the training program and to follow through with evaluation when back on the job. Whereas learning can be readily assessed through conventional pre- and posttest measures, behavior changes are more of a challenge to assess. Failure to use the training back on the job could result from its being unrelated to the job or ineffective or from a lack of opportunity to practice newly acquired skills. All merit investigation. Those tactics frequently used (*8*) to evaluate changes in employee behavior include certification, licensing, and master job performance. Other tactics, discussed later, involve microsampling, control group comparison, critical incidents, and outlier assessment.

Utility of Training

Whereas the immediate outcome to be assessed is some change in behavior, there is little justification for the costs of training unless it has increased productivity or reduced costs. This aspect of evaluation examines productivity and financial data.

STATE OF EVALUATION IN A SAMPLE OF COMMUTER RAIL AGENCIES

Reaction Sheets

A recent survey (McKnight and Rotter, unpublished data) of training at commuter rail agencies in the New York–New Jersey metropolitan area indicated the pervasive use of reaction forms to evaluate training. Although trainees are in a good position to answer questions about the presentation, too frequently reaction forms ask questions that trainees have little background to answer.

Dixon (*9*) details three problems that frequently result from the use of reaction forms: an increased focus on the entertainment value of the course, instructional design decisions based on inadequate information, and reinforcement of the notion of training as passive. To the extent that reaction forms focus on the instructor, instructors change their behavior to enhance their ratings. Because high ratings are linked to factors such as the instructor's being personable and the energy level in the class, the entertainment aspect of a course is amplified. Reaction forms that fail to ask critical questions or that ask questions that cannot be adequately answered by participants become deficient data bases for the construction of design decisions. Finally, the focus on the instructor reinforces the perception that learning is a passive rather than an active process. Despite the shortcomings of reaction forms, other systematic techniques were typically not contemplated by the training departments of the surveyed commuter rail agencies.

Supervisory Observation

Most training departments had contact with management in the operating departments. This contact, though used informally and unsystematically, provided feedback to the training department on the training courses and suggestions about courses that would be needed in the future. However, supervisory observation as a source of evaluation falls short on many counts. It is not solicited in any systematic fashion and is subject to distortions and biases.

Linkage to Performance Appraisal

Nonunionized employees at the commuter rail agencies were evaluated regularly with performance appraisals. These forms typically allowed for suggestions for performance improvement. One of the surveyed agencies designed its appraisal form so that suggested courses could be noted. This agency was experimenting with a plan to tie future appraisals to former notations of recommended courses. That is, when a supervisor suggested a specific course for the employee, the next appraisal would note whether the course had been taken and if improvement had been derived from the course. Other agencies, when asked about this practice, reported that it was not done and that there were no plans for linking performance appraisal to courses taken. Whereas this coupling of training and performance appraisal makes course evaluation more systematic, it is limited to nonunion employees. Moreover, without feedback to the training department, the evaluation will not provide a corrective function.

Behavioral Performance Measures

In addition to commuter rail agencies, one large freight railroad was included in the survey. Its training department reported that it evaluated courses in several ways. It too used reaction forms for all courses, but new courses are evaluated for a number of months with pre- and posttests of knowledge and skills. Generally, these tests indicate a 50 to 60 percent improvement in knowledge and skills. New courses are also evaluated with follow-through interviews of supervisors and trainees about 6 months after trainees finish the course. After this initial phase, only reaction forms are used systematically, with occasional questionnaires sent to supervisors.

In two instances, this training department used behavioral indicators. One involved a training program (referred to previously) to reduce fuel consumption. This lent itself well to evaluation in terms of measurable changes and, in fact, fuel consumption was reduced more than 10 percent. In another instance, a needs analysis indicated that only 100 of 840 locomotive electricians were qualified as electricians. Moreover, locomotives had 28 mean days before failure. With the institution of the new training program for electricians, the mean time to failure increased to 78 days.

This technical training department is currently working on an intelligent system for troubleshooting on air brakes. Technicians will be trained to use this artificial intelligence system on lap-top computers. The director of training noted that, too frequently, wheels are changed when the real problem is in the brakes. By training mechanics to use this newly developed system, saving in parts should be realized. The value of performance indicators as a measure of training lies in the ease with which they can be transformed into measures of efficiency and in management's ready comprehension of the value of training.

BARRIERS TO EVALUATION

Staff Size

The training departments in the five commuter rail agencies consisted of a director and some support staff. Most of the technical training relied on staff from the operating departments. For example, operating examiners might be in charge of locomotive engineer training, and supervisory staff might be responsible for training in the maintenance departments. Because of the small size of the training departments, course development and implementation take the lion's share of time, leaving time only for reaction forms. The freight railroad was the only organization surveyed that had centralized technical training and a large training staff (35 people). Given this commitment to training, it is not surprising that this organization had the most sophisticated evaluation process.

Lack of Performance Standard

Evaluation is based on the notion that measurable change takes place. Failure to specify a way to measure the change and how much change is needed renders evaluation impossible. A problem underlying failure to specify performance standards is lack of comprehensive, current job analyses. The data yielded from a job analysis would indicate not only the skills and knowledge needed to accomplish a task but also the mastery levels needed to accomplish the task effectively.

Evaluation as a Political Issue

In some cases evaluation may be perceived as a political issue that is used either to further some department's agenda or to eliminate programs that are considered frivolous. This perception presupposes that a decision has already been made and that the evaluation is a way to justify the decision. This misuse of evaluation is more likely when evaluation is an afterthought and not an integral part of the training program. Another situation that lends itself to evaluation as justification occurs when pilot testing is neglected. Money and time are committed before the program has been evaluated on a small scale to ascertain whether objectives are being met. Commitment escalates with time and money spent so that pressures for justification become enormous. Situations like this can threaten the integrity of the evaluation process.

CLEARING THE HURDLES OF EVALUATION

Evaluation and Needs Analysis

Evaluation should be considered at the beginning of training development, and this should begin with periodic assessment of instructional needs. The needs assessment sets the plan for developing training programs that are useful to the organization rather than those that are the latest fad. In rail agencies, for example, organizational analysis would consider planned strategic changes that require new skills and knowledge in the work force. The changes may emanate from technology, regulatory legislation, or competitive demands in the environment. In some instances the change might better be met by revisions in the selection of personnel or by redesign of work.

Using Needs Analysis To Build Commitment

If one of the barriers to evaluation is a suspicion that it is a tool for justification, commitment to evaluation can be built during the needs assessment. By incorporating the critical groups into the needs analysis, would-be critics can become stakeholders. Thus, unions that might be opposed to the assessment process should be brought in early. The survey of training and operating departments described here indicated that unions were generally supportive of training programs but less supportive of testing. Collaboration with unions to define instructional needs and establishment of criteria for evaluation can avoid resistance later in the process. Similarly, top management can increase commitment to the training program if it is involved in the setting of broad strategic needs.

Development of Criteria

The criteria should derive from the instructional needs assessment. Mager (*10*) proposes that the criteria describe behaviors that demonstrate the desired skill, conditions under which the trainee will perform, and the lowest limit of acceptable performance. Evaluation should be done at various points in a training program: at the end of classroom instruction, at the end of the on-the-job component, and later on the job itself. Obviously, different standards appropriate to the various stages must be formulated.

The criteria themselves should be evaluated to ensure that they meet tests of reliability and validity. Typically, they are selected on the basis of relevance, completeness, and lack of contamination. Relevance means that the criterion consists of components that are similar to those required to succeed in the job. Completeness considers the extent to which the criterion lacks components found in the job. Contamination deals with elements in the criterion that are unrelated to performance in the job.

Two major groupings of criteria should be considered in designing evaluation: criterion-referenced and norm-referenced measures. Criterion-referenced measures compare an individual's performance with a standard of achievement. Industry standards provide criterion-referenced measures. According to Goldstein (*6*), these are less commonly used in industrial training settings. Norm-referenced measures compare the performance of one trainee with that of others or to norms that have been developed on broader samples, but they say little about the level of skill.

MANAGEMENT AND TRAINING CONCERNS

Goldstein (*6*) describes three complaints that reflect concerns from those involved in training. The trainee's complaint concerns trainees who complete a training program and whose scores on pre- and posttests indicate improvement but who lose their jobs because of inability to perform the work. The trainer's complaint concerns a well-planned, well-implemented training program whose trainees are not permitted to perform their jobs as they were trained. Management's complaint concerns money spent on a training program that worked well for the competition but fails to work for the organization in question.

Each of these complaints reflects problems with the manner in which the criterion was selected. From management's perspective, the ultimate measure of success is dollars resulting from savings or increased productivity. However, a training program that saves money for the competition may not meet the needs of a particular organization because of differences in the work force, work design, methods, or delivery of the program. Though basic skills can be taught with generic programs, technical skills likely to be needed in rail transportation require more tailored instruction.

The trainee and trainer complaints also suggest criterion problems. If trainees complete a training program but still cannot do the job, it is time to look at the job. Has the job changed since the initiation of the program? Has the work force changed substantially since the inception of the training program? Are jobs now held by groups who are deficient in areas required for success on the job? From the trainer's perspective, an additional problem is suggested. If trainees are trained in a method that is not used on the job, then "going by the book" and actual practice must be examined. The problem certainly points to the need for more current job and person analyses.

EVALUATION TACTICS

Kirkpatrick (*11*) has suggested four levels of evaluation: reaction, learning, behavior, and results. Each assesses different aspects of the training process and outcomes. Reaction is mostly related to the training process and gauges the receptivity of trainees to the program and the atmosphere in which the training was delivered. Learning, too, can be a process measure in which the course itself is assessed with an eye toward revising it to establish more effective training. Learning, however, can be an outcome measure in which the trainee is tested on the knowledge and skills acquired. Behavior refers to a measurement of job performance. Kirkpatrick (*11*) notes that just as a good rating on reaction forms does not guarantee that learning takes place, excellent performance on the training tasks does not ensure that the training will affect the way the job is performed. Finally, results relate to the way the training programs affect overall organizational objectives. These utility measures allow translation of outcomes to figures that permit comparisons between ways of training, between formal and informal training, and so forth.

Employee-Centered Evaluation

This level of evaluation examines the impact of training on the individual. Learning can be assessed by comparing knowledge and skills before and after training. Though an experimental design using control groups yields the most convincing data on the effects of training, situations in industry often preclude use of such controls. A more flexible approach to evaluation is a quasi-experimental design that depends on several pretest measures before introduction of the training program. Commuter rail training programs that had apprenticeships regularly tested the trainees on knowledge. Furthermore, FRA-mandated testing could also serve as an evaluation check by linking performance on FRA tests with training performance.

Besides evaluating performance at the end of training, an on-the-job evaluation is essential to gauge whether the acquired skills have been transferred to the job. The difficulty is that most jobs covered by unions do not have systematic performance appraisal. As a surrogate measure, an observation form might be developed for supervisors to complete, or employees themselves might be trained to track ways that training has been used in their jobs through the critical incident technique.

The most promising method, however, of checking on the transfer of skills is by using simulators. Long used in aviation, simulators are just beginning to work their way into locomotive engineer training. They give detailed performance indicators in varied simulated work situations. Simulated work situations are also being created for dispatchers' jobs. The use of models is related to simulations. The technical training department of the surveyed freight railroad has replicated portions of its line to scale. This allows it to simulate various types of signal failure and observe trainees' troubleshooting skills. As more skills are moved from on-the-job training to systematic training, it will become possible to evaluate training performance in greater detail. Underlying all attempts to assess performance is the development of clear-cut performance standards for the job in question.

Focus on Course and Program

To evaluate the effectiveness of a training course or program, one needs to shift the focus from the individual to the group level. Some evaluations will be aggregated individual scores that indicate how the group is doing on the average; others may be organizational indicators that consider time to complete tasks and quality of the work done or that compare this course or program with alternative training.

An intriguing technique for evaluating training that can be applied from medical evaluation is microsampling. In medical microsampling, two doctors review a sample of patient charts to identify problems in patient care. This technique could be applied to car repair and inspection units, in which a sample of repaired or maintained cars or engines could be inspected for problems. If problems are identified, procedures for solutions can be determined, and later reaudits would determine whether the problem has been eliminated.

Another technique from the medical profession is outlier analysis. Outliers are patients whose hospital stays deviate from the norm for that diagnosis. This technique presupposes a good data base that provides normative data. With the proliferation of computers in every area, building such data bases is not unreasonable.

Outlier analysis lends itself to comparisons between and within rail organizations. For use within an organization to evaluate car repair and maintenance, time to failure would be a good index. Use of maintenance information systems for equipment would permit analysis of stock with longer or shorter than the average time to failure. If information is available from other rail lines, between-organization comparisons could be made. Though differences in age of equipment, amount and type of use, and environmental factors detract from direct comparison, they could be taken into consideration and handled through statistical control.

Outlier analysis can be applied to other areas of rail operation as well. It is useful for analysis of customer complaints, accidents, on-time performance, ridership, fuel consumption, and so forth.

Focus on Organization

In most areas of organizations, requests for new equipment or an increase in personnel are accompanied by projections of increased productivity or decreased costs. In human resources, however, the translation of program benefits into dollars is a new phenomenon. Utility analysis concerns detailing the cost of all the factors in training and comparing it with the cost of on-the-job training. To accomplish this, the organization must know the amount of time it takes both trained and untrained workers to reach a standard of performance, the difference in performance between the average trained and untrained worker, and the costs of training for the trainee, the trainer, and the facilities. Cascio (*12*) has worked out formulas that transform this information into monetary factors. Though it is difficult to assign monetary values, failure to do so, Cascio warns, will cause training to be seen only in terms of costs.

EVALUATION AS MANAGEMENT STRATEGY

Despite the increased availability of decision support systems and intelligent systems to aid in decision making, decisions concerning training continue to be based more often on intuition, hunches, and tributes. Money is spent on courses because they have good marketing rather than good content. Questions concerning demonstrated payback are rarely asked.

Detailed Feedback

One advantage of evaluation derives from the development of performance measures, which, in turn, derive from job analysis. Development of these documents will require close attention to the nature of the jobs, how they have changed, and how they can be assessed. The availability of performance measures will give management a keener sense of how job behaviors relate to unit performance. The ability to evaluate performance should permit managers to identify problems early and recommend specific training or remediation for those with substandard performance.

Change Training

Whereas training is increasing across industries and rail is no exception, an irony emerges in that training is becoming bureaucratized (*13*). It is most often administered separately from line operations. Among the five commuter rail agencies surveyed (McKnight and Rotter, unpublished data), the most common location is in the personnel or human resources division. In several agencies, technical and managerial training are housed in separate units. In the large freight rail line, technical training is part of the operations department, and managerial training is part of the human resources department. Technical training had been moved into the operations department after its value had been demonstrated in a program designed to reduce fuel consumption. Separation from operating divisions has obvious advantages: it fosters consideration of long-range training goals and promotes an atmosphere that is different from the daily pressures of work on the line. However, separation makes training vulnerable to the risk that it will not be responsive to operations needs.

Educational Technologies

The professionalization of training is leading to an increase in computer-based instruction, particularly interactive videodisc, in which a videodisc player is interfaced with a computer. The courseware combines text and graphics on a floppy disk with high-quality visual and audio on the videodisc. The presentation is controlled by the program and by the student, who enters responses (input) through the computer keyboard. Touch-sensitive screens provide another source of input.

Advantages and Disadvantages of Videodisc Technology

Interactive videodisc technology incorporates the best features of computer-based instruction, such as individualized pace of instruction, active learning mode, and immediate feedback. Students can see the outcomes of various decisions and, through the flow of the presentation, understand the consequences of their choices. It further incorporates evaluation into the learning process, because the computer keeps track of the students' choices and provides a record both to the students and the trainer.

Professionalization of training could lead to a proliferation of packaged training programs. Such packaged programs may meet the need for basic skills in various technical areas, but they do not meet the need for training on specialized equipment. Large railroads can afford to develop custom-crafted training programs using the latest in education technology, but smaller railroads face greater difficulties. Once educational developers have generated programs for larger railroads, they may promote these programs to smaller railroads. Use of interactive videodisc could be especially appealing to smaller railroads, because it would permit fairly sophisticated technical training programs without maintenance of a large training staff. However, if such training programs do not meet specific needs, they will not result in the expected improvements in performance. Systematic evaluation programs aid in avoiding such mistakes.

Building Commitment to Training

Systematic evaluation can build and enhance managers' commitment to training by including them in the process of evaluation (*14*). Managers have a stake in both the outcome and the development of training. If training is to be needs- or user-driven, so must evaluation. Consequently, managers should participate in all phases of training, from needs assessment to course development to evaluation. If the starting point for change in a training program is evaluation, managers should be part of the groups that produce the objectives and criteria against which training will be evaluated. Their other major role is that of evaluators who assess the extent to which training has improved job performance.

The evaluation should be sensitive to the questions managers have concerning training and should be presented in a useful time frame and manner. Presentation of evaluation findings in a timely and intelligible way will enhance their use by managers in making decisions concerning the place of training in long-range plans for the agency.

SUMMARY

The role and status of training evaluation in rail transit were reviewed. Three forms of evaluation—process, outcome, and utility—were considered. Training evaluation in a sample of commuter rail agencies was examined. Findings indicate that reaction forms are ubiquitous. One rail agency is attempting to link training evaluation to performance appraisal for its nonunion employees. The most sophisticated use of evaluation was found in a large freight railroad.

Barriers to the conduct of more thorough evaluations are the lack of training staff, nonexistent or outdated performance standards, and a perception that evaluation is a tool to justify decisions already made. Needs and job analyses were recommended for reducing the barriers.

Techniques of training evaluation that could be used in the rail industry were described. Evaluation can be done at the employee, program, and organization levels. Evaluation was also discussed as it relates to management strategy. Advantages include facilitation of detailed feedback to management, its use for changing training, and its capacity to build commitment to training among managers. The relative benefits and drawbacks of educational technologies were considered.

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Methodology for Evaluating Out-of-Direction Bus Route Segments

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Out-of-direction (OOD) travel is a deviation from the main line of a fixed-route bus service. Deviations can help improve accessibility to potential riders along the OOD segment, but they can also lead to loss of through riders because of increased travel time. This is especially true of discretionary riders, for whom travel time is important in the decision to use transit. The issue is how to objectively evaluate the trade-off between increased accessibility and impact on through riders. The San Diego Metropolitan Transit Development Board contracted with Crain and Associates to develop a formal methodology for evaluating OOD segments. The development of the methodology is discussed, and examples of how it works are provided.

Out-of-direction (OOD) travel is defined as a deviation from the main line of a fixed-route bus service (see Figure 1). An OOD segment is the portion of the route that deviates. OOD segments improve accessibility to areas off the main line, benefiting riders who wish to travel to or from places along the OOD segment. Such deviations generally cause higher operating costs and inconvenience to through riders (passengers already on the bus who do not alight along the OOD segment) as a result of longer travel times.

Implementation of OOD segments may provide better access to persons along the segment, but it may also lead to the loss of through riders. On routes with a high volume of through riders, deviations from the main travel path may deter ridership and may prevent the discretionary rider, for whom travel time is an important consideration, from choosing to use transit. OOD travel complicates bus routings for the user, which is a further disincentive to the use of transit. A cost/benefit analysis of an OOD segment, therefore, must assess the trade-off between accessibility and the effect on through ridership. The question is how to objectively evaluate this trade-off.

The San Diego Metropolitan Transit Development Board (MTDB) recently hired Crain and Associates, a consulting firm, to develop a formal methodology for assessing OOD segments. MTDB staff will apply the methodology to existing deviations and future requests for such deviations. The development of the methodology and how MTDB will use it for route evaluation are discussed.

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DESCRIPTION OF MTDB

MTDB was created in 1975 to plan and construct transit guideway facilities in the southern urban portion of San Diego County. MTDB is also the policy-setting and coordinating agency for all transit services and facilities in its jurisdiction.

MTDB is an independent agency governed by a board of directors, whose 15 members include representatives of the various local jurisdictions and the county and one representative appointed by the governor of California. The two largest operators in the region, San Diego Transit Corporation (SDTC) and San Diego Trolley, Inc. (SDTI), are wholly owned subsidiaries of MTDB.

Complementing SDTC and SDTI in providing fixed-route services in the MTDB area are Chula Vista Transit, National City Transit, San Diego County Transit System, and contract operators. Whereas these other operators are separate entities, all fixed-route operators are part of the Metropolitan Transit System (MTS). MTS was designed to provide a unified transit system to the public. The MTS logo is displayed on all transit vehicles, public timetables, and information brochures so that the user is aware that a coordinated route, fare, transfer, and information system is available.

SDTC, which has 100,000 daily riders on 31 routes and is the region's largest carrier, was the focus of the OOD methodology development. Its routes serve 1.6 million people over a 390-mi^2 area.

BACKGROUND OF THE SAN DIEGO EXPERIENCE

Topography and land use patterns are often at odds with providing convenient, easily accessed transit service. The MTDB service area is made up of many canyons and mesas, which have led to circuitous street patterns and to the location of many neighborhood and commercial areas off main arterials. Combined with this is the growing suburban nature of much of San Diego's development, with low-density land uses and "walled-in" neighborhood designs. The result is that many areas are not within a convenient walking distance of the major arterials, where bus routes would normally operate.

Not surprisingly, MTDB and SDTC receive numerous passenger requests to deviate a bus route to neighborhoods and areas where commerce, employment, and institutions are con-

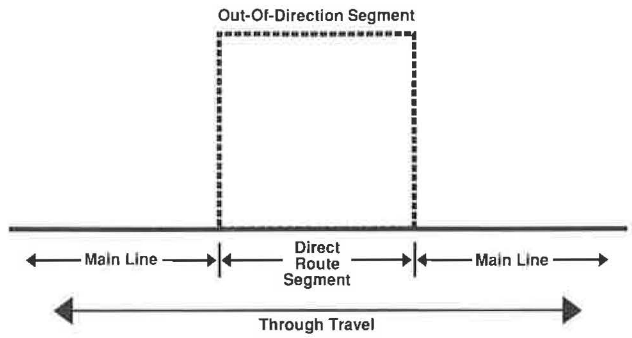

FIGURE 1 OOD segment.

centrated. Many such changes have been implemented. Over time, the result has been that some routes have developed up to five OOD segments.

Recent MTDB direction has been to discourage additional route deviations and to eliminate some existing OOD segments. These actions have been taken to improve operating efficiency and encourage more through ridership. As in many other transit systems, the problem has been the lack of a formal methodology for evaluating OOD segments. To remedy this situation, MTDB hired Crain and Associates to develop such a methodology. The goal was to incorporate the methodology into a formal MTDB policy that would guide MTDB in evaluating existing and proposed OOD segments.

METHODOLOGY

Any OOD segment, whether existing or proposed, should be evaluated by an objective set of criteria. The evaluation method presented here consists of three steps for existing OOD segments (see Figure 2):

1. Rate OOD segments on the basis of time delay to through passengers.
2. Determine whether not operating an OOD segment could save bus operator resources.
3. Analyze the operating cost and productivity of the OOD segment and consider qualitative factors that may influence the decision to retain or discontinue the segment.

For a proposed OOD segment, the goal is to assess whether the potential OOD ridership would justify its addition. The time delay formula developed as part of Step 1 would be used in the determination.

Step 1—OOD Impact Index

Index Formula

The first step in the analysis is to measure the trade-off between the time-inconvenience of OOD deviations to through passengers and the benefit of the deviation to OOD riders. The trade-off is a function of the number of through passengers, the additional time for the OOD segment, and the number of passengers served by the segment. An OOD impact index measures the trade-off in this relationship. The index is a measure of the extra travel time that through passengers face for each OOD passenger served. It is equal to the ratio of through riders to OOD riders multiplied by the additional travel time:

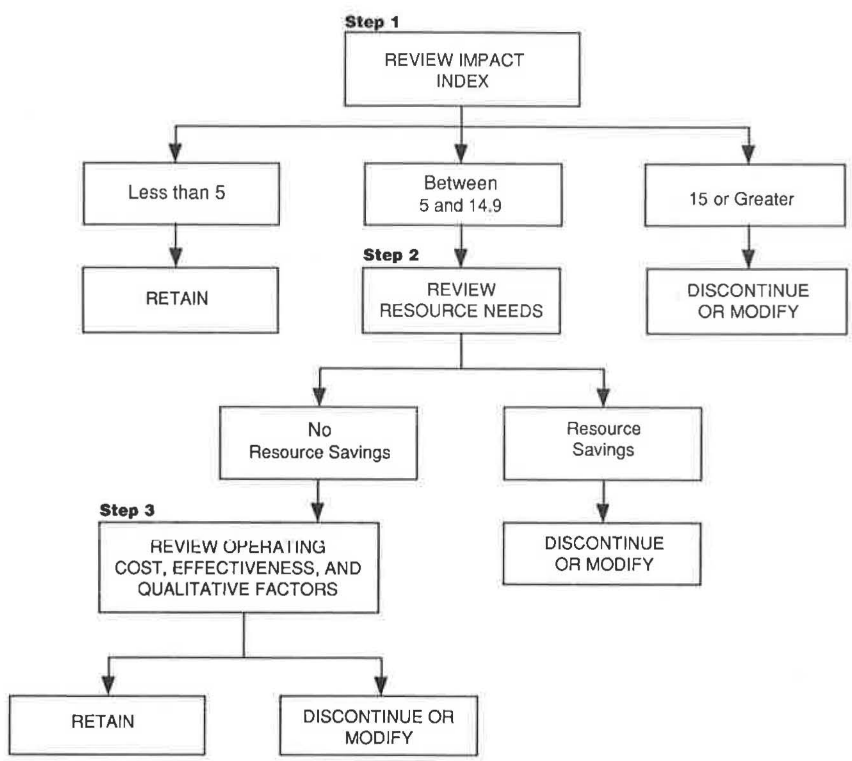

FIGURE 2 OOD travel analysis methodology.

OOD impact index

= (through ridership × OOD travel time)/OOD ridership

where

OOD impact index = a weighted measure of time expressed in minutes,
through ridership = the difference between the number of passengers on the bus before the OOD segment and the number of passengers alighting on the OOD segment,
OOD travel time = the net increase in travel time required to operate the OOD segment rather than the direct alignment, and
OOD ridership = all boardings and alightings on the OOD segment beyond 0.25 mi from the main line. Passengers boarding and alighting within 0.25 mi of the main line are considered to be served by that line, with or without the OOD segment.

The following are examples of the index.

Consider an OOD route segment midway in a route that adds 4 min of travel time. One hundred passengers board and alight the bus on the OOD segment each day, and 500 passengers travel through the segment to reach points on either side. The OOD impact index for this segment is calculated as follows:

OOD impact index

= (500 passengers × 4 min)/100 passengers = 20 min

An index value of 20 min is high, representing a significant inconvenience to through passengers. The index may be more clearly understood if it is viewed as through-passenger delay per unit of OOD level of activity. Through-passenger delay is high at 2,000 passenger-min in this example, and OOD activity is low at 100 passengers. Consequently, much delay to through passengers is being caused to provide service to a few OOD passengers.

Consider another OOD segment of similar length in which through ridership is 100 and OOD activity is 200. This segment might be near the route's terminal, where ridership is relatively light. However, the OOD segment itself is highly productive, with 100 boardings and 100 alightings daily, for a total of 200 passengers. The OOD impact index is calculated as follows:

OOD impact index

= (100 passengers × 4 min)/200 passengers = 2 min

The index value for this segment is low, as indicated by the minimal inconvenience caused to through passengers relative to passenger activity on the segment.

The OOD impact index is valuable in part because it provides a quantitative reflection of passenger perceptions. A long detour through a neighborhood where few passengers board or alight is likely to be perceived more keenly than a detour through a neighborhood where boarding and alighting activity is intense.

High OOD impact indexes are likely to be found (*a*) where through ridership is high and OOD activity is low and (*b*) where through ridership is high and a lengthy route detour is required. Low indexes are likely to be found (*a*) in an OOD segment requiring little travel time where OOD passenger activity is moderate and through ridership is modest and (*b*) in a highly productive OOD segment serving a major activity center, such as a trolley station or employment complex, located a short distance from the route.

Interpretation of Index Values

The OOD impact formula used here was taken from the formula used by the Tri-County Metropolitan Transit District (Tri-Met) in Portland, Oregon. Other transit agencies in the United States and Canada reportedly have similar measures. Tri-Met uses the equation to help it determine whether to operate an OOD deviation. If the index value is greater than 5, the deviation will generally not be operated unless there are mitigating circumstances. This limit was chosen by Tri-Met as the maximum delay to which through passengers should be subjected under normal circumstances.

The Tri-Met guidelines and field testing conducted during the study suggested three groupings of the OOD index for MTDB:

- An index value between 0 and 4.9 indicates that the number of OOD passengers is large compared with the number of through passengers, or that the diversion time is small, or both. Segments with indexes in this range are not likely to deter through ridership.
- An index value between 5 and 14.9 indicates some inconvenience to through passengers that may affect through ridership.
- An index value of 15.0 or above indicates that the OOD deviation is inconvenient to through passengers and has an adverse impact on through ridership.

The upper range values were not established by quantitative analysis. It was believed that a general range of values should exist in which factors other than the OOD impact index influence the decision to retain or delete an OOD segment. The 5-to-14.9 range and Steps 2 and 3 of the process, discussed later, are used. The value 15 was chosen as the cutoff point that clearly indicates unacceptability.

Existing OOD Segments For existing OOD segments, the OOD impact index is a good indicator of the acceptability of an OOD deviation to through passengers. Continued service for segments with indexes below 5 is probably well justified, and segments with indexes of 15 or more should be discontinued. In the 5.0-to-14.9 range, other factors, such as resource needs, operating costs, service effectiveness, and qualitative factors, should be considered in making the determination. These factors are addressed in Steps 2 and 3.

New OOD Segments During the evaluation of a new OOD segment, potential ridership on the segment is unknown. In this case, the OOD impact index formula is used to determine how much ridership is required to justify implementation. An OOD impact index value of 4.9 represents the upper limit for a segment that clearly does not deter through ridership, so the formula for determining that ridership level is

OOD ridership needed

= (through ridership * OOD travel time)/4.9

If such a level of OOD ridership can reasonably be expected, the OOD segment should be considered for implementation.

Step 2—Resource Needs

A review of resource needs is the second step in the OOD evaluation process. Transit routes require a certain number of vehicles and operators to provide service. SDTC estimates that saving one vehicle operator translates into average annual labor cost savings of $45,000. The resource savings are calculated by determining the route running time with and without the OOD segment and then determining whether the running time saving is sufficient to reduce the bus operator requirement.

Bus operator reductions are likely under three circumstances:

1. Single lengthy OOD segments,
2. Several OOD segments on the same route where the combined running time saving results in a reduction of resources, and
3. OOD segments on routes with recovery times in excess of the 7 min required by SDTC's labor agreement.

Lengthy OOD segments can produce an operator saving if the extra running time is equivalent to the headway between buses. For example, an 8-min OOD segment could save one bus if the route operates 15-min headways, because the 8-min impact occurs twice per round trip. In practice, such OOD segments are unlikely to occur, and if they do, they are likely to have a high impact index, which would eliminate them in the first step of the evaluation process. However, several routes have more than one OOD segment. The combined travel time penalty of several segments may be equivalent to a running time saving that allows a reduction of one or more bus operators.

Routes with excess recovery time provide another opportunity to save resources. Excess recovery time is the extra time at the end of each bus trip that is not required for driver layover or other operating needs. Currently, SDTC requires 7 min of recovery time at each terminal. Most routes have extra time, because vehicle requirements are based on a stepwise progression that adds an operator if the overall running time exceeds an even multiple of the headway. There is an opportunity for saving resources when the excess recovery time is high in relation to the route headway. In such cases the time saved by not operating an OOD segment, combined with excess recovery time, may reduce resources. For example, a route with a round-trip running time of 185 min (including required recovery time) and service at 30-min intervals would require seven vehicles. If 5 min per round-trip could be saved by not operating an OOD segment, running time would be reduced to 180 min, requiring only six vehicles to operate the route.

In many situations the time saved is not sufficient to reduce the number of bus operators. However, the cumulative effect of discontinuing multiple OOD segments may be that sufficient time is saved to reduce the bus operator requirement. In addition, even a small time saving may provide a margin that can be used to improve on-time performance, schedule timed transfers, or extend the route. These qualitative benefits are considered in Step 3.

The purpose of Step 2 is to determine whether there are resource savings associated with the OOD segment. If resources can be saved, the segment should be considered for discontinuance or modification. If resources cannot be saved, the analysis proceeds to Step 3.

Step 3—Cost, Effectiveness, and Qualitative Factors

A review of operating cost, effectiveness, and qualitative factors of OOD segments is the third step in the evaluation process. OOD segments that have an impact index between 5.0 and 14.9 and cannot yield resource savings would be evaluated according to these criteria. The purpose of this step is to determine the savings in operating cost that can be achieved by discontinuing the OOD segment and whether a route is more or less productive without the segment. The indicator of productivity used for this analysis is the number of boarding passengers per revenue mile (PPM). The measure is calculated at the route level rather than for the OOD segment. Route-level calculation of productivity has advantages and a disadvantage. The advantages are as follows:

- The combined effect of multiple OOD segments can be easily calculated because the passengers and miles data base is common to all segments.
- Point deviations (in which a route deviates from and returns to the main line at the same location) can be measured. It is impractical to measure productivity at the OOD level for a point deviation OOD segment because the direct-route mileage is zero.
- New ridership produced by travel time reductions is measured at the route level because it originates at many points along the route, not just on the OOD segment.

The disadvantage of calculating productivity at the route level is that OOD passengers and miles may be small compared with route passengers and miles, and a change in productivity that is significant at the OOD level may appear insignificant at the route level. As long as this limitation is understood, the advantages of route-level calculation of productivity make it preferable to OOD-level calculation.

Operating Cost

SDTC annual operating costs by route were used to establish the existing cost of each route. The operating cost of the route without the OOD segment was determined by calculating the annual operating miles saved and multiplying the value by the marginal operating cost. Marginal operating cost is the cost related exclusively to miles operated: fuel, lubricants, tires, and maintenance. SDTC currently estimates the marginal cost to be $0.50/mi.

Effectiveness

Effectiveness was assessed by measuring route productivity with and without the OOD segment. PPM was selected as the effectiveness indicator for the following reasons: (*a*) revenue miles will change with the discontinuance of any OOD segment, whereas revenue hours will generally change only if there are resource savings; and (*b*) running times generally vary throughout the day, depending on traffic and demand, which complicates measurement of the indicator.

The formulas for measuring productivity (PPM) for the OOD segment and direct alignments are as follows:

PPM (with OOD) = (OOD segment existing annual boarding passengers) ÷ (annual revenue miles for OOD segment)

PPM (without OOD) = (existing route annual boarding passengers − OOD segment annual boarding passengers + direct routing annual boarding passengers + through riders added annually because of travel time savings) ÷ (existing route annual revenue miles − OOD segment annual revenue miles + direct routing annual revenue miles)

Passengers Passenger boarding volumes for existing routes with OOD segments were drawn from ride check data. Passenger volumes without the OOD segment are based on passenger gains and losses resulting from discontinuing the OOD segment: new ridership on the direct route that replaced the OOD segment, ridership loss from discontinuing the OOD (on the basis of existing ride check data), and gain in through ridership from reducing travel time.

Through ridership on the main line is likely to increase because of travel time savings. The increase can be estimated by using the following travel time–demand elasticity formula:

Additional through ridership = (difference in travel time between OOD segment and direct routing * through ridership * 0.30) ÷ (average passenger trip length for entire route)

where the difference in travel time and the average passenger trip length are in minutes and 0.30 is an elasticity coefficient, meaning that the percentage increase in through ridership is 0.30 times the percentage decrease in travel time. For example, a 25 percent decrease in travel time would produce a 7.5 percent increase in ridership. This factor was used because of the lack of a local elasticity factor; it is a common standard.

Revenue Miles The lengths in miles of OOD segments and direct route segments were determined from field checks. The mileage saving for discontinuing the OOD segment was calculated by subtracting direct route miles from OOD miles. The mileage saving was multiplied by daily trips to produce daily mileage, which was annualized. The annualized mileage saving was then deducted from annual route revenue miles provided by SDTC to produce the net revenue miles to be operated if the OOD segment were discontinued.

Effectiveness Assessment The PPM measures for the route with the OOD segment and with the direct alignment were compared to determine any productivity improvements. If productivity improves when an OOD segment is eliminated, the segment should be considered for discontinuance or modification. If route productivity declines when an OOD segment is eliminated, continuation of the segment is reasonable. In all cases, qualitative concerns should also be addressed, as discussed next.

Qualitative Concerns

Qualitative factors should be considered in the final step of the evaluation process for questionable OOD segments.

One of the goals of any transit system is to provide transportation to captive riders (riders who depend on transit for personal mobility because they lack an automobile or the ability to drive). Service to an area that includes a large number of captive riders should be analyzed carefully. If an OOD segment to such an area is to be discontinued, it may be desirable to explore ways to maintain accessibility.

Consideration should also be given to activity centers that are served by an OOD segment. Such centers may include hospitals and clinics, social service agencies, supermarkets, and schools. It may be desirable to maintain a minimal level of transit service to these locations. Nonetheless, these factors must be weighed against the disadvantages of continuing the OOD segment.

EXAMPLES

Three examples demonstrate how the methodology works. The first OOD segment has a low OOD impact index, and the second has a high OOD impact index. The third segment has an OOD impact index in the midrange, so Steps 2 and 3 are required to fully assess the segment. Quantitative results from the analysis are given in Table 1.

Low OOD Impact Index

Convoy Court is an OOD segment on a local route (Route 25) connecting Clairemont Mesa with San Diego's Centre City. The OOD segment is shown in Figure 3. The main route deviates a block from the main line to serve employment locations on Convoy Court and a Kaiser Permanente clinic at the junction of Shawline Street and Clairemont Mesa Boulevard. Passenger boardings and alightings on the segment

TABLE 1 OOD SEGMENT ANALYSIS

	OOD Segment		
	Route 25: Convoy	Route 16: Aero	Route 25: Linda Vista
STEP 1: IMPACT INDEX			
Time Factor (in minutes)			
o OOD Segment	3	6	6
o Direct Routing	2	2	2
o Net Time for OOD Segment	1	4	4
OOD Segment Passengers	104	86	117
Through Passengers	274	298	825
OOD Impact Index*	2.6	13.9	28.2
STEP 2: RESOURCES			
Resource Savings (Bus Operator)	None	None	None
STEP 3: COST EFFECTIVENESS			
Marginal Cost Savings**	$2,200	$6,400	$10,400
Passengers per Revenue Mile			
o OOD Segment	1.90	2.18	1.90
o Direct Routing	1.92	2.28	2.01
o Percent Change	1.1%	4.7%	5.6%

** - OOD Impact Index is the net through rider time impact per unit of OOD travel.*
*** - Marginal "out-of-pocket" operating costs calculated at $45,000 per bus operator and $0.50 per revenue mile.*

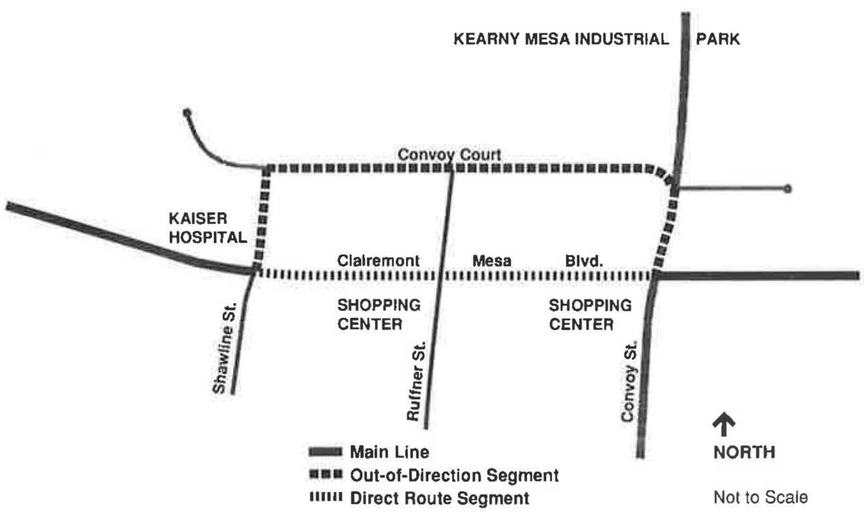

FIGURE 3 Convoy Court OOD segment.

are high. Through passengers on the main route are relatively low because the segment is located near the outer terminal. These circumstances result in a low OOD impact index of 2.6, which indicates that the segment should be retained and that no further analysis is necessary. It is interesting to note, however, that the results of Steps 2 and 3 (given in Table 1) indicate that no resource savings can be achieved with such a short OOD segment and that route productivity will increase negligibly if the segment is discontinued. This is consistent with the low OOD impact index, based on a small OOD time penalty and high OOD productivity.

High OOD Impact Index

Linda Vista is an OOD segment located on Route 25 between two major activity centers: the Fashion Valley Transit Center and the Kearny Mesa employment complex (see Figure 4). Passenger boardings and alightings on the segment are relatively low. Through ridership on this segment of Route 25 is heavy. Finally, the time penalty for the OOD segment is high, because a significant deviation is required.

The combination of the three factors substantially affects through riders. Not only is the segment a lengthy deviation from the main route, but also it is perceived as unproductive because of the absence of strong passenger activity. The resulting OOD impact index of 28.2 indicates that this segment should probably be discontinued. Although Steps 2 and 3 are not required in this case, neither step contradicts the findings of Step 1. Whereas Step 2 indicates that no resources could be saved by discontinuing the segment, Step 3 indicates a significant marginal cost savings and a potential improvement in service effectiveness.

Midrange OOD Impact Index

Figure 5 shows Aero Drive, an OOD segment near one end of Route 16. The OOD impact index for this segment is 13.9. This value is well above 4.9, which would indicate retention of the segment, and below 15, the level at which it would be automatically considered for discontinuance or modification. The high index value is caused by three factors: the segment is long, there is relatively little boarding and alighting on the segment, and through ridership is relatively high.

The high value indicates that the lengthy deviation, combined with low OOD passenger activity, is an inconvenience to through riders. Step 2 in Table 1 indicates that no resource savings are achieved by discontinuing the segment. The deviation is too short to reduce the route operating requirement by a full bus operator.

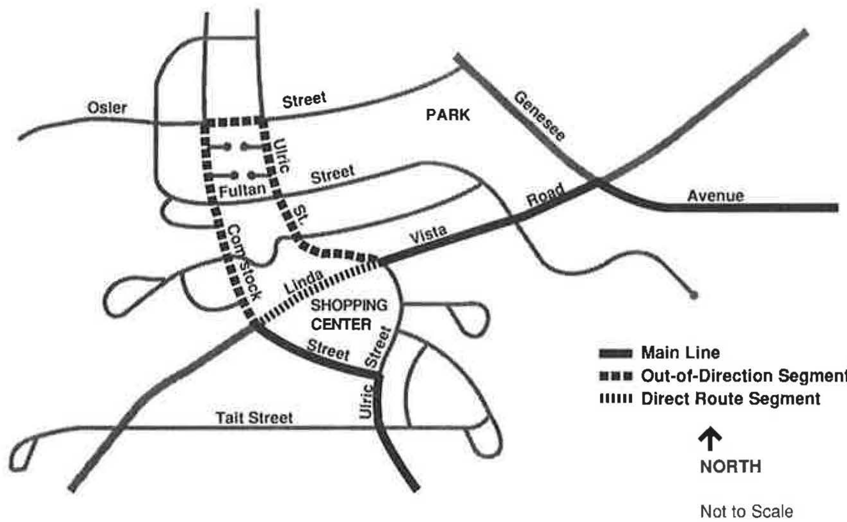

FIGURE 4 Linda Vista OOD segment.

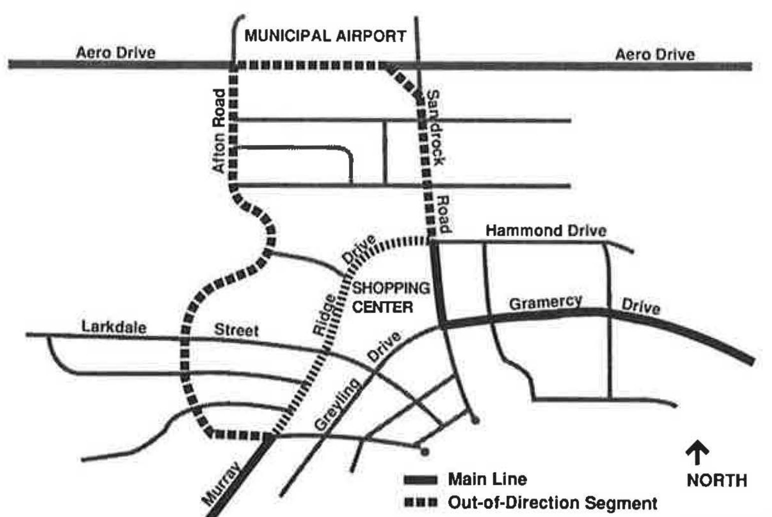

FIGURE 5 Aero Drive OOD segment.

Step 3 indicates that the service effectiveness of Route 16 would improve if the OOD were discontinued. PPM will increase by nearly 5 percent, because more miles will be saved than passengers lost. The saving in miles is evident from the length of the OOD segment. The small net change in passengers is the result of three factors: (*a*) most existing passengers will continue to walk to the main route, (*b*) the direct-route segment will generate additional riders at a neighborhood shopping center on the direct alignment, and (*c*) the time saving from operating on the direct alignment will produce a significant increase in through riders.

The cost analysis in Step 3 indicates that there are significant marginal operating cost savings to be gained from discontinuing this OOD segment and that the service effectiveness of the route will also improve. The findings indicate that the segment should be considered for discontinuance unless qualitative factors indicate otherwise. Qualitative factors further support discontinuance of the segment:

- The 4-min time saving will improve on-time performance on Route 16 by reducing running time.
- A bus resource can potentially be saved if Aero Drive is discontinued concurrently with another Route 16 OOD segment in Mission Valley. This resource could be used to improve service frequency on Route 16.
- Passenger transfer connections with Route 25 at Aero Drive are negligible, and an alternative transfer connection with Route 25 is available at a nearby transit center.
- Direct service to the neighborhood shopping center can be provided if the segment is discontinued.
- Low-income housing in the neighborhood is as close to the proposed direct alignment as it is to the current OOD alignment, thereby affording accessible service for transit-dependent residents.

NEXT STEPS

As indicated earlier, MTDB intended to develop a formal policy for evaluating OOD segments. Such a policy was adopted by the MTDB's board of directors in August 1990 (MTDB Policy Number 39, "Out-of-Direction Bus Routings Policy"). The policy informs the public on how such service requests are to be analyzed and provides the board of directors with a valuable tool in deciding an OOD segment's value. During the coming months, the methodology will be applied to several existing OOD segments identified by the board of directors for analysis. On the basis of the results, the board will decide whether to retain, delete, or modify them.

Whereas this methodology will provide a basis for analyzing the merits of an OOD segment, deciding which travel time elasticity factor to use remains a problem. No local elasticity factor exists, and limited research in this area is available nationwide. Given the lack of better data, the standard elasticity coefficient of 0.30 was used. However, as the methodology is applied and decisions are made on eliminating existing OOD segments or adding new ones, an opportunity to assess the local travel time elasticity factor for such service changes will arise. MTDB plans to monitor this area closely during the next few years in the hope of developing a local elasticity factor that can be used to strengthen both the OOD methodology and MTDB's route evaluation process in general.

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Integration of Fixed- and Flexible-Route Bus Systems

SHYUE KOONG CHANG AND PAUL M. SCHONFELD

Temporally integrated bus systems, in which fixed-route services are provided during higher-demand periods and flexible-route services are provided during lower-demand periods, are investigated with analytic optimization models. Threshold analysis is used to determine which option is preferable for a given demand pattern and to identify favorable situations for integrated operation. Optimized vehicle sizes, route spacings, zone areas, and service headways are obtained and compared for fixed-route, flexible-route, and integrated systems.

Conventional bus services are characterized by their fixed routes and schedules and are generally thought to require substantial demand densities to be economically viable; paratransit services have flexible routes or schedules (or both) and are considered most suitable for low-density areas or time periods (*1–11*). The potential for improving public transportation services through coordinated operation of paratransit and conventional transit systems has been recognized (*12,13*). However, most studies on integration of public transportation systems have focused on spatially integrated systems of conventional modes, such as park-and-ride operation coordinated with mass transit systems (*14,15*) and integrated feeder bus–rail transit systems (*16–18*), which are commonly applied in U.S. urban transit systems.

Various types of integration of conventional bus and paratransit services have been attempted in several suburban areas with varying levels of success (*19–23*). Control strategies and issues related to the implementation of integrated systems have also been discussed and evaluated (*10,13,24–27*). However, studies concerning the temporal integration of conventional bus and paratransit services, in which conventional fixed-route services are provided during higher-demand periods and flexible-route door-to-door services are provided during lower-demand periods, are mostly limited to conceptual and qualitative analyses (*5,10,12,25*). A simulation model has been developed and used to evaluate temporal integration options for cities with populations of less than 10,000 (*28*). It was concluded that the net operating costs of alternative dial-a-ride/fixed-route services comprising a mixed bus fleet of 45-seat buses for peaks and 12-seat buses for off-peaks are better than those of either fixed-route or dial-a-ride services. However, the alternatives compared were all prespecified rather than optimized.

In this paper an analytic approach is applied to design and evaluate temporally integrated systems. Two feeder bus systems, a conventional fixed-route and a flexible-route subscription bus system, are considered. Threshold evaluation based on analytic optimization models (*11*) is used to determine favorable situations for operation of temporally integrated systems, and mathematical models of total system costs for an integrated system are formulated and analyzed. Optimized results are presented for vehicle size, route spacing, headway, and service zone areas.

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BUS SYSTEM CHARACTERISTICS

Figure 1 shows the service areas and their specific route structures for the two feeder systems. The variables and the typical values used in the numerical analysis are given in Table 1. The bus systems with either fixed or flexible routes are assumed to connect a rectangular area of length L and width W to a major generator (e.g., a transportation terminal or an activity center) that is J mi from that area. Analytic optimization models for these two feeder systems developed in earlier work (*11,29*) are applied. The models provide optimized solutions in closed form with time-dependent demand and supply characteristics (vehicle operating cost and speed) and over multiple periods. Route structures and operation attributes for the two services are briefly described.

Fixed-Route Services

For fixed-route services, the service area is divided into N zones with route spacing $r = W/N$, which is fixed over time, as shown in Figure 1a. A vehicle round-trip in period t consists of (*a*) a line-haul distance J traveled at express speed yV_t from the major terminal to the service area; (*b*) a delivery route L mi long traveled at local speed V_t along the centerline of the zone, stopping for passengers every s mi, with an average delay of d_t hr for each stop; and (*c*) reversal of the previous two phases to collect passengers and carry them to the terminal.

Flexible-Route Services

The route structure for the flexible-route subscription service is shown in Figure 1b. The service area is divided into N_t equal zones, each of which has area $A_t = LW/N_t$. This service zone structure is more flexible than that for fixed-route service and is allowed to vary over time. In each time period, feeder buses travel from the terminal a line-haul distance J and an average distance $L/2$ mi at express speed yV_t to the center of each

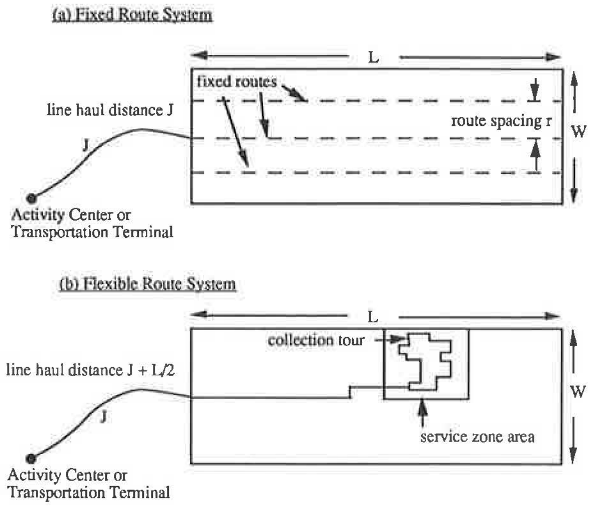

FIGURE 1 Fixed- and flexible-route feeder bus systems.

zone. They collect passengers at their doorsteps through a tour of n_t stops with length E_t at local speed V_t. The values of n_t and E_t are endogenously determined using Stein's formula (*30,31*). To return to their starting point, the buses retrace an average of $L/2 + J$ mi at yV_t mph. It is assumed that buses operate on preset schedules with variable routing designed to minimize the tour distance E_t and that tours are routed on a rectangular grid street network. Tour departure headways are assumed to be equal for all zones in the service area and uniform within each period. For both service types the average wait time equals a constant factor z_1 times the headway h_t. As in fixed-route service, vehicle layover time and external costs of bus services are assumed to be negligible.

On the basis of the assumptions that n_t points are randomly and independently dispersed over an area A_t and that an optimal traveling salesman tour has been designed to cover these n_t points, the collection distance E_t in an optimized zone may be approximated by the following result of Stein (*30,31*) for dial-a-ride routing:

$$E_t = \phi(n_t A_t)^{1/2} \quad (1)$$

In Equation 1, ϕ is constant and has been estimated to be 0.765 for a Euclidean metric (*31*). Applications of Equation 1 are discussed by Larson and Odoni (*32*) and Daganzo (*33*).

The demand density q_t during each time period t is assumed to be obtained from empirical distributions of demand over time, as shown in Figure 2. The demand distribution over time typically represents a daily demand cycle, as in the four-period demand distribution shown in Figure 2, although it may also be used to analyze noncyclical demand conditions, such as long-term growth patterns. The demand is also assumed to be deterministic, uniformly distributed over time during each specified period, and uniformly distributed over space within each specified service area. The number and duration of time periods are unlimited.

The analytic results for the optimal route structures (route spacings and zone sizes), vehicle sizes, and service headways for the two services derived by Chang and Schonfeld (*11*) are used in this analysis. These optimality relations are presented

TABLE 1 VARIABLE DEFINITIONS

Variable	Definition	Baseline Value
a_t	fixed cost coefficient for period t ($/hr)	-
	a_1, a_2, a_3, and a_4 = 30, 15, 15, and 15, respectively.	
A_t	service zone area in period t (sq. miles)	-
b_t	variable cost coefficient for period t ($/seat hr)	-
	b_1, b_2, b_3, and b_4 = 0.4, 0.2, 0.2, and 0.2, respectively.	
C	total system cost ($/day); = $C_o + C_u$	-
C_o	operator cost ($/day)	-
C_u	total user cost ($/day)	-
C_v	user in-vehicle cost ($/day)	-
C_w	user wait cost ($/day)	-
C_x	user access cost ($/day)	-
d_t	average delay per stop during period t (hr/stop)	0.01
D_t	avg. bus round trip time during period t (hrs)	-
E_t	distance of one collection tour in period t (miles)	-
F_t	fleet size in period t (vehs)	-
g	access speed (miles/hr)	2.5
h_t	headway in period t (hr)	-
J	line haul distance (miles)	8.0
L	length of corridor (miles)	4.0
m	number of periods in the analysis time frame	4
n_t	number of pickup stops in one collection tour during period t	
N	number of zones	-
N_t	number of zones in period t	-
p_t	bus load factor at peak load point during period t	-
q_t	potential demand density in period t (trips/sq. mile/hr)	
	q_1, q_2, q_3, and q_4 = 120, 60, 10, and 5, respectively	
r	route spacing (miles)	-
s	stop spacing (miles)	0.25
T_t	duration of period t (hrs)	
	T_1, T_2, T_3, and T_4 = 3, 6, 6, and 9, respectively.	
u_t	avg. no. of passengers per pickup point during period t	1.2
U	equivalent line haul distance (miles) = 2J/y + L/y	-
v	value of in-vehicle time ($/hr)	5.0
V_t	bus speed during period t (miles/hr);	
	V_1, V_2, V_3, and V_4 = 10, 12, 15 and 15, respectively	
w	value of wait time for conventional bus ($/hr)	10.0
w'	value of wait time for paratransit ($/hr)	8.0
W	width of corridor (miles)	3.0
x	value of access time ($/hr)	10.0
y	express ratio = express speed/local speed	2.0
z_1	ratio of wait time/headway	0.5
z_2	ratio of access distance/route spacing	0.25
Z	composite variable defined in Table 2	-
ϕ	constant in the collection distance equation	1.15
π	composite variable defined in Table 2	-
δ	composite variable defined in Table 2	-
θ	composite variable defined in Table 2	-

in Table 2. Different effects of demand density and other system parameters can be identified on the basis of the analytic results for single-period cases. From the results for a single period, it is shown that the optimized vehicle sizes are proportional to the ⅓ power and the ⅕ power of demand density for fixed- and flexible-route services, respectively. Fig-

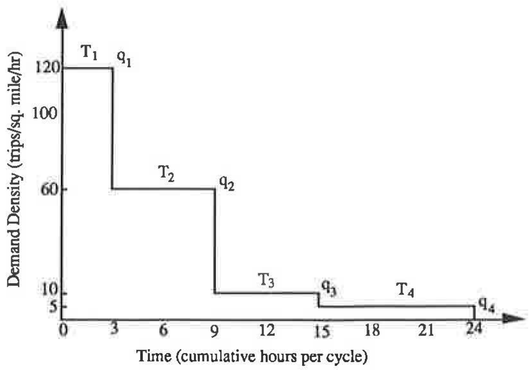

FIGURE 2 Demand pattern assumed in numerical example.

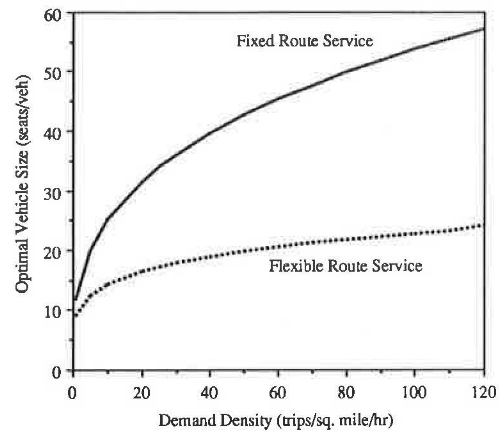

FIGURE 3 Vehicle size comparison for fixed- and flexible-route services.

TABLE 2 ANALYTIC RESULTS FOR OPTIMIZED BUS SYSTEMS

(1) Fixed Route Service	Multiple Periods	Single Period
Vehicle Size (seats/veh)	$\left(\frac{gL\pi\delta^2}{z_1 z_2 w x}\right)^{\frac{1}{3}}$	$\left(\frac{gLqa^2D^2}{z_1 z_2 w x p^3}\right)^{\frac{1}{3}}$
Route Spacing (miles)	$\left(\frac{z_1 w g^2 \delta}{z_2^2 x^2 L\pi}\right)^{\frac{1}{3}}$	$\left(\frac{z_1 w g^2 a D}{z_2^2 x^2 L q}\right)^{\frac{1}{3}}$
Headway (hrs)	$\left(\frac{p_i}{q_i}\right)\left(\frac{z_2 x \pi^2 \delta}{z_1^2 w^2 g L}\right)^{\frac{1}{3}}$	$\left(\frac{z_2 x a D}{z_1^2 w^2 g L q}\right)^{\frac{1}{3}}$
(2) Flexible Route Service	**Multiple Periods**	**Single Period**
Vehicle Size (seats/veh)	$\left(\frac{U^3 Z^3}{2 z_1 w \phi^2}\right)^{\frac{1}{5}}$	$\left(\frac{U^3 a^3 u q}{2 z_1 w \phi^2 p^3 (b+vp/2)^2 V}\right)^{\frac{1}{5}}$
Zone Area (sq. miles)	$p_i S^* \left(\frac{2 z_1 w V_i u_i^{1/2}}{\phi q_i (a_i + b_i S^* + v p_i S^*/2)}\right)^{\frac{2}{3}}$	$\left(\frac{8 a u z_1^3 w^3 V^3 U^3}{\phi^4 (b+vp/2)^2 q^3}\right)^{\frac{1}{5}} \theta^{-\frac{2}{3}}$
Headway (hrs)	$\left(\frac{\phi(a_i + b_i S^* + v p_i S^*/2)}{2 z_1 w V_i u_i^{1/2} q_i^{1/2}}\right)^{\frac{2}{3}}$	$\left(\frac{a\phi}{4 z_1^2 w^2 V^2}\right)^{\frac{2}{5}} \left(\frac{1}{q}\right)^{\frac{1}{3}} \theta^{\frac{2}{3}}$

Note:

$$\theta = \left(\frac{2 z_1 w a^2 p^3 V}{u^{5/2} q}\right)^{1/5} + \left(\frac{U^3 (b+vp/2)}{u^{3/2}}\right)^{1/5} \quad Z = \frac{\sum_i a_i q_i T_i / p_i V_i}{\sum_i [q_i^2 (b_i + v p_i/2)^2 / u_i V_i^2]^{1/3} T_i} \quad \pi = \frac{\sum_i q_i T_i}{\sum_i p_i T_i} \quad \delta = \frac{\sum_i a_i D_i q_i T_i / p_i}{\sum_i q_i T_i}$$

TABLE 3 COMPARISON OF FIXED-ROUTE, FLEXIBLE-ROUTE, AND INTEGRATED SYSTEMS

Systems	Fixed Route	Flexible Route	Integrated System
Vehicle Size (seats/veh)	48	17	37
Route Spacing (miles)	0.867	-	0.683
Zone Area (sq. miles)	-	0.681 1.350 4.201 6.110	- - 4.054 5.021
Headway (hrs)	0.115 0.164 0.401 0.554	0.208 0.183 0.247 0.295	0.113 0.160 0.265 0.295
Fleet Size (no. of vehs)	48 29 10 7	115 60 13 8	63 37 13 9
Total Cost ($/day)	60,390	61,633	59,390
Avg. Cost ($/trip)	6.100	6.226	5.998
Avg. Operator Cost ($/trip)	1.422	2.224	1.693
Avg. User Cost ($/trip)	4.678	4.002	4.305
Avg. Wait Cost ($/trip)	0.906	0.819	0.737
Avg. In-Veh Cost ($/trip)	2.655	3.183	2.754
Avg. Access Cost ($/trip)	1.117	0	0.814

ure 3 compares optimal vehicle sizes for the two services. It is shown that for demand densities between 1 and 120 trips per square mile per hour, the optimal vehicle size ranges from 9 to 24 seats per vehicle for flexible-route services and from 12 to 58 seats per vehicle for fixed-route services. As mentioned, the vehicle size is less sensitive to demand densities for flexible-route services than for fixed-route services.

The numerical results for the two services are presented in Table 3 on the basis of the demand pattern shown in Figure 2. The average costs are $6.10 and $6.23 per trip for fixed- and flexible-route services, respectively. On the basis of these results, fixed-route services are preferable to flexible-route services for the given demand pattern and other assumptions. Table 3 and Figure 4 indicate that the average user cost for fixed-route services is considerably higher than that for flexible-route services, whereas the operator cost for fixed-route services is considerably lower than that for flexible-route services. Operators, therefore, on the basis of their own costs, would strongly favor fixed-route services. The optimized ve-

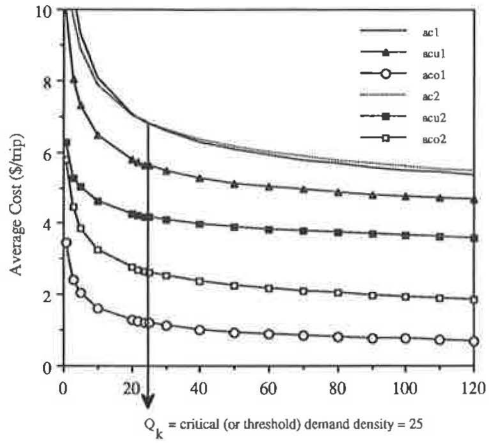

FIGURE 4 Average cost comparison for fixed- and flexible-route services.

hicle sizes are much smaller for flexible-route services (17 seats versus 48 seats for fixed routes), thus requiring a much larger fleet size (115 rather than 48 vehicles in the peak period).

THRESHOLD ANALYSIS

A threshold analysis is used to determine which service type is preferable in which situations. Average cost (dollars per trip) is used to identify the critical demand density Q_k, below which the flexible-route service is preferable and above which the fixed-route service is preferable. In Figure 4 the optimized average costs of the two services are compared for a wide range of demand densities. The two average cost functions intersect at a demand density of 25 trips per square mile per hour, at which the average cost is $6.8 per trip. Hence, for the given parameter values and related assumptions, flexible-route services are preferable for demand densities below 25 trips per square mile per hour, which is considered to be the critical demand density. However, because the average cost functions for the two services intersect at very slight angles, the threshold value (e.g., 25 trips per square mile per hour) is quite sensitive to various system parameters. System parameters other than demand density, such as service area, operating cost, speed, and value of time, may also be analyzed to determine the values for which one service is better than the other. Sensitivity analyses (*11*) indicate that the relative advantages of flexible-route services generally increase with smaller service areas, higher operating speeds, lower fixed bus costs, lower incremental costs of vehicle size, higher values of access and wait time, and lower values of in-vehicle time.

With the critical demand density, the demand distribution can help determine under what circumstances fixed- or flexible-route bus services should be used exclusively. Figure 5 shows a transit daily demand distribution in which the maximal demand density is q_{max} and the minimal demand density is q_{min}. This demand distribution has been processed from the original distribution to produce a distribution of flow versus duration. There are three possible interrelationships among the threshold demand density, maximal demand density, and minimal demand density:

1. If the flexible-route paratransit service is preferable to the conventional bus service at the highest demand density q_{max} (i.e., the threshold demand density is q_a), it is preferable to operate the paratransit service exclusively. (See Figure 5, Case *a*.)
2. If the fixed-route bus service is better than the flexible-route bus service at the lowest demand density q_{min} (i.e., the threshold demand density is q_b), fixed-route service should be operated exclusively. (See Figure 5, Case *b*.)
3. If the fixed-route service is better at $q = q_{max}$ but the flexible-route service is appropriate at $q = q_{min}$ (i.e., the threshold demand density q_c is between q_{max} and q_{min}), an integrated system will be preferable. (See Figure 5, Case *c*.)

Conditions for determining which service is preferable were discussed by Adebisi and Hurdle (*9*), but no strategy for the integration was developed, because only steady demand conditions were modeled. Multiperiod analytic optimization models for designing integrated systems are presented below.

TEMPORALLY INTEGRATED SYSTEMS

From the threshold analysis, the range of demand densities for which flexible- or fixed-route services are preferable and the situations in which an integrated system is preferable can be identified. In the numerical examples (Figure 4), the flexible-route services were preferable to the fixed-route services at demand densities below 25 trips per square mile per hour. Because the demand distribution includes periods with demand above and below 25 trips per square mile per hour, a temporally integrated system should be preferable. The integrated system provides fixed-route services in the higher-demand periods (e.g., Periods 1 and 2 in the numerical example shown in Figure 2) and flexible-route services during the lower-demand periods (Periods 3 and 4).

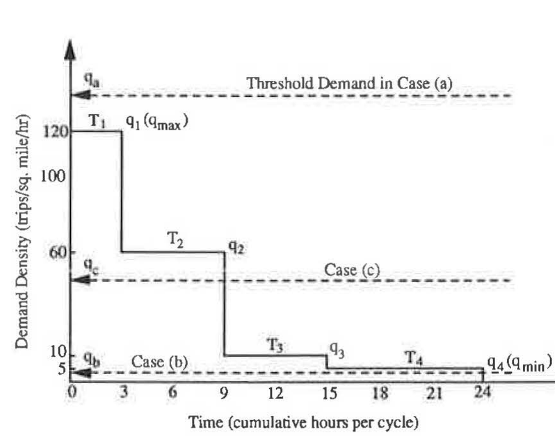

FIGURE 5 Various cases of threshold demand density.

This optimization approach seeks to determine the combination of vehicle size, route spacing, zone sizes, and service headways that minimizes total system cost (C). C, including the operator cost (C_o), user wait cost (C_w), user access cost (C_x), and user in-vehicle cost (C_v), can be expressed as a function of the decision variables [i.e., vehicle size (S), route spacing (r), zone area (A_t), and headway (h_t)] and system parameters:

$$C = \sum_{t=1}^{j-1} [C_o(S, r, h_t, K_t) + C_w(h_t, K_t) + C_x(r, K_t) + C_v(K_t)] + \sum_{t=j}^{m} [C_o(S, A_t, h_t, K_t) + C_w(h_t, K_t) + C_v(S, A_t, h_t, K_t)] \quad (2)$$

where $K_t = (B_t, V_t, T_t, L, W, w, x, v)$ is a set of system parameters consisting of operating cost (B_t); operating speed (V_t); duration of time periods (T_t); service area dimensions (L and W); access speed (g); and values of wait, access, and in-vehicle time (w, x, and v, respectively).

The first part of Equation 2 is the cost of operating fixed-route services during Periods 1 to $j - 1$. The second part is the cost of operating flexible-route services during Periods j to m. The access cost is assumed to be negligible because users are picked up and dropped off at their doorsteps. Such a formulation relies on the previous threshold analysis to determine that fixed-route services are preferable in Periods 1 to $j - 1$, whereas flexible-route services are preferable in Periods j to m. This total cost function can be considered a combined cost function for the two types of service.

The following type of linear function for bus operating cost used by Jannson (*34*) and by Oldfield and Bly (*35*) is adopted for the total cost function:

$$B_t = a_t + b_t S \quad (3)$$

where S is the vehicle size in seats per vehicle and a_t and b_t are parameters that may be estimated statistically. Certain relationships among vehicle size, zone size, and headway are also specified in the total cost function. For fixed-route service, they are expressed as

$$h_t = p_t S / r L q_t \quad (4)$$

and for flexible-route service as

$$h_t = p_t S / A_t q_t \quad (5)$$

In Equations 4 and 5 p_t is the bus load factor at the peak load point. With these relationships, the total system cost of Equation 2 can be formulated for the integrated system as follows:

$$C = \sum_{t=1}^{j-1} \frac{LWD_t q_t T_t (a_t + b_t S)}{p_t S} + \sum_{t=1}^{j-1} \frac{w z_1 p_t S W T_t}{r} + \sum_{t=1}^{j-1} x z_2 L W q_t T_t \left(\frac{r + s}{g}\right) + \sum_{t=1}^{j-1} v L W q_t T_t M_t + \sum_{t=j}^{m} \frac{LWUq_t T_t (a_t + b_t S)}{V_t p_t S} + \sum_{t=j}^{m} \frac{LWq_t T_t \phi (a_t + b_t S) A_t^{1/2}}{V_t (u_t p_t S)^{1/2}} + \sum_{t=j}^{m} \frac{vLWUT_t}{2V_t} + \sum_{t=j}^{m} \frac{vLWq_t T_t \phi (A_t p_t S)^{1/2}}{2V_t u_t^{1/2}} + \sum_{t=j}^{m} \frac{w' z_1 LWT_t p_t S}{A_t} \quad (6)$$

Detailed derivations of these relationships are presented by Chang (*36*).

The variables and parameters are defined in Table 1. Different values of wait time, denoted as w and w′ for fixed- and flexible-route services, respectively, are defined for the two services. They allow a lower value of time to be used for indoor waiting at the origin, which may occur for flexible-route pickup. For this integrated system a single vehicle size is jointly optimized for both fixed- and flexible-route services, whereas the route spacing (r) and service zone area (A_t) are optimized separately for fixed- and flexible-route services.

The solution procedure for this problem is the combination of the solution procedures for the separate fixed- and flexible-route systems (*11*). Detailed derivations for integrated systems are provided by Chang and Schonfeld (*11*) and Chang (*36*). Equation 7 is obtained by solving the first derivatives of the total cost function:

$$\frac{\beta_1}{S^2} - \frac{\beta_2}{S^{1/2}} - \frac{\beta_3}{S^{1/3}} = 0 \quad (7)$$

where

$$\beta_1 = \sum_{t=1}^{j-1} \frac{a_t D_t q_t T_t}{p_t} + \sum_{t=j}^{m} \frac{a_t U q_t T_t}{p_t V_t} \quad (8)$$

$$\beta_2 = \sum_{t=1}^{j-1} q_t T_t \left(\frac{z_1 z_2 w x \sum_{t=1}^{j-1} p_t T_t}{gL \sum_{t=1}^{j-1} q_t T_t} \right)^{1/2} \quad (9)$$

$$\beta_3 = (2w' z_1 \phi^2)^{1/3} \sum_{t=j}^{m} T_t \left\{ \frac{q_t^2 (b_t + v p_t/2)^2}{u_t V_t [1 + a_t / S(b_t + v p_t/2)]} \right\}^{1/3} \quad (10)$$

If $j = 1$, Equation 7 includes only flexible-route services. In that case the optimized vehicle size shown in Table 2 for flexible-route services can be used. If $j - 1 = m$, the problem is reduced to finding the optimal solution for only fixed-route services, and the analytic results shown in Table 2 for fixed-route services can be applied.

Equation 7 is not difficult to solve numerically, but it has not been solved in closed form. After the optimal vehicle size is obtained, the optimal route spacing (r^*) for fixed-route services and zone area (A_t^*) for flexible-route services can be obtained with the following equations:

$$r^* = \left(\frac{z_1 w g S^* \sum_{t=1}^{j-1} p_t T_t}{z_2 w L \sum_{t=1}^{j-1} q_t T_t} \right)^{1/2} \quad (11)$$

$$A_t^* = p_t S^* \left(\frac{2 z_1 w' V_t u_t^{1/2}}{\phi q_t (a_t + b_t S^* + v p_t S^*/2)} \right)^{2/3}$$

$$t = j, j + 1, \ldots, m \qquad (12)$$

The service headway for different periods providing fixed- or flexible-route services can also be obtained by substituting the optimized vehicle size (S^*) and route spacing (r^*) or zone area (A_t^*) into Equations 4 and 5:

$$h_t^* = \frac{S^* p_t}{r^* L q_t} \qquad t = 1, 2, \ldots, j - 1 \qquad (13)$$

$$h_t^* = \frac{S^* p_t}{A_t^* q_t} \qquad t = j, j + 1, \ldots, m \qquad (14)$$

A compromise vehicle size for providing fixed-route services in the higher-demand periods and flexible-route services in the lower-demand periods can be determined with Equation 6.

NUMERICAL CASES

Baseline Value Results

For the four-period example shown in Figure 2, the fixed-route services are provided in the first and second periods. and the flexible-route services are provided in the third and fourth periods. Therefore, Equation 7, in which β_2 and the first term of β_1 are components from the first and second periods, whereas β_3 and the second term of β_1 are components from the third and fourth periods, becomes

$$\frac{33{,}027.5}{S^2} - \frac{78.1}{S^{1/2}} - \frac{39.5}{S^{1/3}} = 0 \qquad (15)$$

By solving Equation 15, the optimal vehicle size for the integrated system is found to be 37 seats per vehicle. By substituting the optimal vehicle size into Equations 11, 12, 13, and 14, respectively, the optimal route spacing, zone area, and headways for the integrated system can be obtained, as given in Table 3.

Comparisons of the temporally integrated systems with pure fixed- and flexible-route systems yield the following observations:

1. The optimized vehicle size of 37 seats for the integrated system lies between those for the two pure systems (48 and 17 for fixed- and flexible-route systems, respectively). Thus, the optimized fleet size of 63 vehicles for the integrated system also lies between those for the two pure systems (48 and 115). It can be verified from Equation 7 that when the demand density and duration of the third period increase, the optimal vehicle size for the integrated system decreases.

2. The average cost for the integrated system is indeed lower than for either pure system. However, its average user cost and the average operator cost both lie between the corresponding pure system values. The cost reduction offered by the integrated system cannot be very high for the systems analyzed in the example, because the average cost functions (Figure 4) for the two pure systems are quite close.

3. The optimal average operator and user costs ($1.693 and $4.305 per trip, respectively) for the integrated system also lie between those for the two pure systems, whereas the optimal average wait cost ($0.737 per trip) is lower than for either pure system.

Effects of Various Demand Patterns

Three demand patterns, which have the same total demand but different demand fractions in Periods 2 and 3, are shown in Figure 6. Case 1 is the previously computed baseline example. The difference in demand between Periods 2 and 3 decreases in Case 2 and increases in Case 3. Table 4 presents the optimized average costs, vehicle sizes, and fleet sizes for the three cases.

Table 4 indicates that the average costs for integrated systems are lower than for pure systems in all three cases, although the decreases in average costs are small in the cases presented here. Vehicle sizes for both pure systems are nearly the same for different demand patterns. However, they vary considerably for integrated systems. Similar results are found for fleet size.

CONCLUSIONS

Temporally integrated systems in which fixed-route services are provided during higher-demand periods and flexible-route services are provided during lower-demand periods were evaluated analytically and numerically. Threshold analysis was

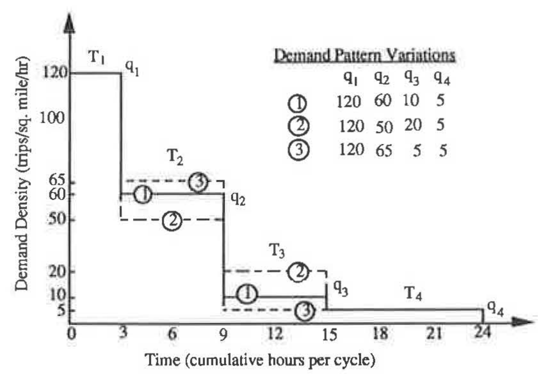

FIGURE 6 Alternative demand patterns analyzed.

TABLE 4 OPTIMIZED AVERAGE COST, VEHICLE SIZE, AND FLEET SIZE FOR THREE DEMAND DISTRIBUTIONS

	Type of System		
Case	Fixed-Route	Flexible-Route	Integrated
Optimized Average Cost ($/trip)			
1	6.100	6.226	5.998
2	6.148	6.302	6.062
3	6.048	6.207	5.946
Optimized Vehicle Size			
1	48	17	37
2	48	16	33
3	48	17	41
Optimized Fleet Size			
1	49	115	63
2	49	121	70
3	49	115	57

used to identify the range of demand densities for which purely fixed- or flexible-route services are preferable and the situations in which integrated systems are preferable. It was shown that the threshold is sensitive to system parameters.

Numerical results indicate that the optimal vehicle size in integrated systems (37 seats per vehicle) is a compromise between the optimal vehicle sizes for pure fixed-route and pure flexible-route services (48 and 17 seats per vehicle, respectively). More important, the average system cost per trip for integrated systems can be lower than for either pure system. However, if the total costs per trip for fixed- and flexible-route alternatives are close, the integrated system cannot offer costs that are much lower than for either pure system. In realistic applications, the benefits of temporal integration are expected to increase as the relative duration of low-demand periods (in which flexible-route services are preferable) increases.

Further studies should consider operation and control strategies for transitions between the two service types in an integrated system. Mixed rather than homogeneous bus fleets for integrated operation are also worth analyzing. Further research may consider demand elasticity and many-to-many demand patterns.

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Downtown Space for Buses—The Manhattan Experience

HERBERT S. LEVINSON, LAWRENCE LENNON, AND JERRY CHENG

The limit of acceptable express bus service in Manhattan is defined. Where additional buses might be accommodated is shown on the basis of system capabilities and passengers' destinations. At present, there is little space for additional express buses during peak hours in the Manhattan central business district in Madison, Fifth, and Sixth avenues in Midtown and along Broadway and Church Street in Lower Manhattan. Volume-capacity analyses indicate that setting limits on the number of express buses is not practical at present, because bus volumes entering the Manhattan hub during peak hours have declined.

The express buses that serve New York City and surrounding areas in Westchester, Nassau, and Suffolk counties receive and discharge their passengers on streets and avenues in the Manhattan central business district (CBD). Buses serving New Jersey via the Holland Tunnel also have on-street collection and distribution. The Port Authority Midtown bus terminal provides off-street loading and unloading for most New Jersey buses.

Most express buses in Midtown concentrate along Madison, Fifth, and Sixth avenues in the heart of the office district. Similarly, express buses in Lower Manhattan concentrate on the only two continuous streets—Broadway and Church Street.

Concern about the effects of express buses on Manhattan streets has grown during the past decade. Many questions have been raised about the desirability and practicality of adding more express buses on Midtown and downtown Manhattan streets, including the following: Can more express buses be accommodated on Manhattan CBD streets? Should limits be imposed on the number of express buses entering Manhattan by sector or just on specific streets? What street management changes are necessary to better serve existing express buses or accommodate additional buses? Is it practical to increase express bus volumes on crosstown streets or peripheral avenues? Can capacity for additional express buses be provided by reducing the number of local buses on key avenues?

This paper addresses these concerns and questions. The limits of acceptable bus service in the Manhattan CBD are defined. Local and express bus flows as they relate to the Manhattan street system are analyzed, bus volumes and capacities are compared, and changes in bus operations and street traffic management to improve service and permit increased bus flows are identified. Where additional buses might be accommodated is shown on the basis of street system capabilities and passengers' destinations.

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ANALYSIS STEPS

The analysis included the following steps.

1. Travel characteristics of express and local bus passengers were reviewed to assess the practicality of rerouting service.
2. Trends in the number of buses and bus passengers entering the Manhattan CBD were analyzed to identify the magnitude and nature of past and probable future changes.
3. The number of peak-hour buses crossing key east-west screen lines in Midtown and Lower Manhattan was estimated. These flows provided a basis for volume-capacity analyses.
4. Capacities were estimated on a street-by-street basis to define limits of acceptable bus service.
5. These limits were compared with peak-hour bus volumes to see where additional buses might be accommodated.
6. The additional buses that could be accommodated by expanding the bus lane system, rerouting buses, or building a bus terminal were estimated.
7. The additional buses from Steps 5 and 6 were added to the peak bus flows on the CBD cordon, from which possible cordon limits were identified.
8. Finally, the policy implications of adding buses and ways to improve the use of downtown bus space were identified.

TRAVEL PATTERNS AND ATTITUDES

The travel patterns and attitudes of New York City express and local bus riders were obtained from surveys conducted by the New York City Department of City Planning (NYC DCP) during mid-1989. Approximately 1,900 express passengers were surveyed on their trip into Manhattan, and approximately 1,300 local bus riders were interviewed as they boarded buses on Midtown avenues at or near 50th Street. The survey results are summarized as follows.

Local Bus Passengers

Approximately half of all local bus passengers surveyed were on work trips, 16 percent were on shopping trips, and 15 percent were on business trips. More than 80 percent were able to use the subway for their trip. The reasons cited for not using the subway were (*a*) subway is less convenient, 43 percent; (*b*) buses are safer, 30 percent; and (*c*) buses are more comfortable, 27 percent.

The short travel distances of most local bus passengers—median distances of 20 to 26 blocks, or 1.00 to 1.25 mi—

reflect the convenience afforded by the local bus service. Such trips are not easily transferable to subway lines because of the time lost walking to and from and entering and leaving subway stations.

Thus, there appears to be much less duplication of local bus-subway service than a review of transit route maps might suggest. Each mode has its own market and catchment area, and neither is a substitute for the other.

Express Bus Passengers

Most express bus passengers (63 percent) traveled 5 min or less to their destination. Once they left the bus in Manhattan, 93 percent walked to their destination, and 7 percent used other means. If the express bus service were not available, 80 percent would use subways or suburban rail lines, 12 percent would come by car, and 8 percent would use vans. Most express bus passengers were former subway or railroad riders. About 54 percent of the express bus passengers cited convenience as the main reason for using express buses. Next in order of importance were safety, 21 percent; comfort, 13 percent; and speed, 7 percent.

Destinations of the express bus passengers surveyed are mapped in Figure 1. About 67 percent reported destinations in Midtown Manhattan. Another 19 percent reported Lower

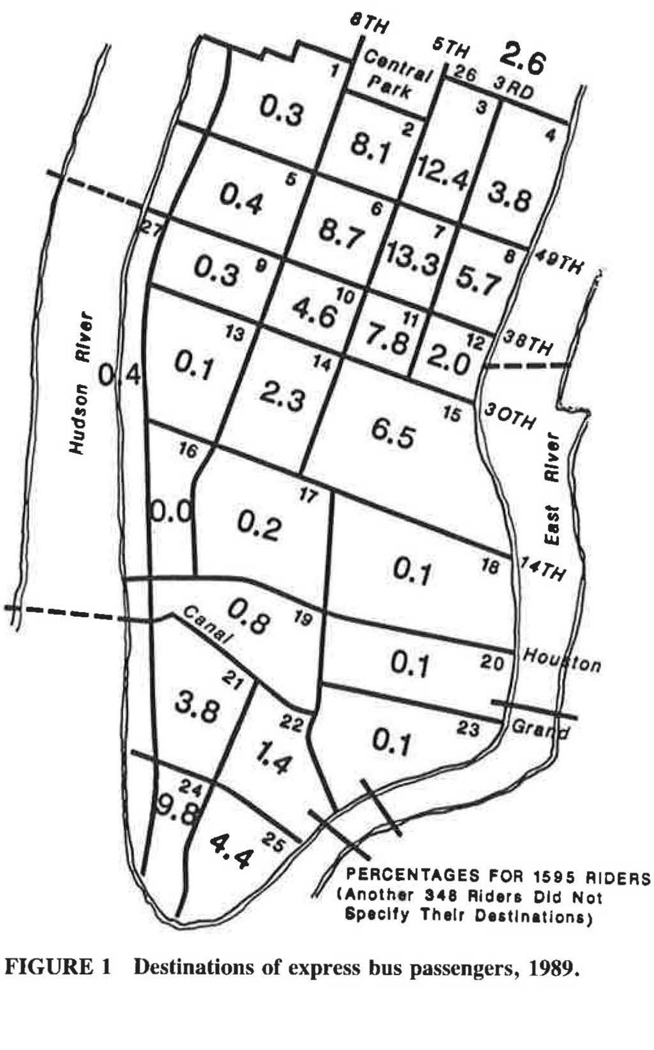

FIGURE 1 Destinations of express bus passengers, 1989.

Manhattan destinations; 11 percent reported destinations in the Valley; and 3 percent reported destinations north of 63rd Street. Thus, Midtown Manhattan appears to be the main focus of express bus passengers.

More than 8 out of every 10 express bus riders with Midtown destinations were traveling to places located between Third and Eighth avenues. The other two riders were going to places east of Third Avenue or west of Eighth Avenue. The destinations of Midtown passengers were distributed as shown in the table below.

Destination	*Percentage*
Third to Fifth avenues	49.7
Fifth to Eighth avenues	31.8
East of Third Avenue	17.0
West of Eighth Avenue	1.5
Total	100.0

Thus, the present concentration of express bus routes on Madison, Fifth, and Sixth avenues reflects the large concentration of passengers' destinations along these blocks. Placing express buses on avenues that are peripheral to the Midtown office core is not practical because most of these avenues are too far from where people want to go.

The Midtown area located between Third and Eighth avenues accounted for 42 percent of all workers' destinations in 1980 compared with 55 percent of all reported express bus passengers' destinations in 1989.

VOLUMES AND PATTERNS OF EXPRESS BUSES IN MANHATTAN

Cordon and screen-line counts of local and express buses in Midtown and Lower Manhattan conducted by the New York Metropolitan Transportation Council and the New York City Department of Transportation (NYCDOT) were analyzed to determine the magnitudes and patterns of local and express bus flow, identify trends in express volumes on Manhattan streets, and assess the impacts on each Manhattan avenue.

Daily Bus Volumes Entering Manhattan Hub

The patterns of express and local bus passengers and vehicles entering the Manhattan hub (i.e., Manhattan south to 60th Street) on a business day in the fall are given in Table 1. The number of daily express bus passengers entering the hub grew steadily from 134,563 passengers in 1977 to a peak of 206,364 passengers in 1984, an increase of 53 percent. However, during the period 1984 to 1988, express bus ridership decreased by 16.8 percent, to 171,819 daily riders.

The number of express riders coming from New Jersey increased steadily between 1977 and 1988, from about 85,200 to 122,600. In contrast, the number of express bus riders coming from the Bronx, Brooklyn, Queens, and Westchester peaked in 1984 and has dropped steadily since.

The maximum number of express buses entered the Manhattan hub in 1986—some 7,751 buses. Of this total, 68 percent came from west of the Hudson River, 30 percent from New York City, and 2 percent from Westchester. In 1988, 7,174 buses entered the hub, a 7.4 percent decline from 1984.

TABLE 1 EXPRESS AND LOCAL BUS PASSENGERS AND VEHICLES ENTERING THE HUB ON A FALL BUSINESS DAY

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Bus Passengers												
Express Bus												
New York City	46,859	52,519	51,139	60,361	62,505	62,102	62,473	79,472	67,448	61,834	53,404	47,088
West of Hudson	85,194	83,618	85,490	89,879	90,094	108,129	114,217	123,673	131,100	127,299	121,550	122,600
North of NYC	2,510	2,580	2,610	2,682	2,596	3,021	3,063	3,219	2,672	2,342	2,132	2,131
Total	134,563	138,717	139,239	152,922	155,195	173,252	179,753	206,364	201,220	191,475	177,086	171,819
Local Bus	98,297	89,697	92,210	100,321	88,472	101,718	101,217	86,131	96,127	75,556	72,278	70,513
Total Passengers	232,860	228,414	231,449	253,243	243,667	274,970	280,970	292,495	297,347	267,031	249,364	242,332
Bus Vehicles												
Express Bus												
New York City	1,591	1,360	1,315	1,665	1,526	1,602	1,802	2,440	2,217	2,357	2,002	1,846
West of Hudson	3,535	3,546	3,564	3,663	3,232	3,639	4,199	4,639	5,140	5,286	5,069	5,219
North of NYC	108	106	109	115	126	127	129	124	125	108	115	109
Total	5,234	5,012	4,988	5,443	4,884	5,368	6,130	7,203	7,482	7,751	7,186	7,174
Local Bus	3,435	3,259	3,168	3,316	3,114	3,395	3,336	2,701	3,192	3,535	3,084	3,304
Total Buses	8,669	8,271	8,156	8,759	7,998	8,763	9,466	9,904	10,674	11,286	10,270	10,478

Source: Hub-Bound Travel 1988, New York Metropolitan Transportation Council

Total Peak-Hour Bus Volumes Entering and Leaving the Hub

Almost 1,770 buses entered the hub during the 8 to 9 a.m. morning peak hour in 1985, compared with 1,630 in 1987 and 1,480 in 1988. The number of buses leaving the hub during the 5 to 6 p.m. afternoon peak hour reached a maximum of almost 1,530 in 1985 and then dropped to 1,410 in 1987 and 1,370 in 1988.

Similar trends were noted for express bus volumes into and out of the hub. The number of inbound buses reached a maximum of about 1,510 in 1985, declining to almost 1,400 in 1987 and 1,225 in 1988. The afternoon peak outbound bus volume dropped from 1,310 in 1985 to about 1,190 in 1987 and 1,160 in 1988.

The largest declines occurred across the 60th Street cordon. They reflect population and demographic changes, subway service improvements, new subway cars, and growing traffic congestion.

Peak-Hour Buses Crossing Selected Screen Lines

The critical capacity "crunch" for buses on Manhattan streets and avenues is within the CBD at points of major passenger boarding and alighting. This is because the ability of curb lanes to handle passengers and buses at key boarding points determines the capacity of the system. Accordingly, analyses were made of bus flows across the 60th Street, 44th Street–50th Street, and Maiden Lane–Liberty Street screen lines during the two peak hours.

60th Street Screen Line

The distributions of express and local buses by avenue across the 60th Street screen line are given in Tables 2 and 3 for the 1987 morning and evening peak hours, respectively. The concentrations of inbound buses along Madison Avenue are apparent. Fifth Avenue carried 78 percent of the total inbound express buses, and Madison Avenue carried 79 percent of the total outbound express buses.

44th Street–50th Street

Tables 4 and 5 give the number of peak-hour local and express buses on each Manhattan avenue across the 44th Street–50th Street screen line (for conditions between 1986 and 1988). These tables indicate a major concentration of express buses

TABLE 2 EXPRESS AND LOCAL BUS VOLUME CROSSING 60TH STREET SCREEN LINES BY FACILITY, 8 TO 9 A.M. PEAK HOUR, INBOUND, 1987

60TH STREET SECTOR	EXPRESS BUS	LOCAL BUS	TOTAL
FDR DRIVE	3	0	3
YORK AVENUE	10	16	26
2ND AVENUE	0	29	29
LEXINGTON AVENUE	14	32	46
FIFTH AVENUE	87	59	146
BROADWAY	6	54	60
COLUMBUS AVENUE	2	17	19
WEST END	0	8	8
TOTAL	122	215	337

TABLE 3 EXPRESS AND LOCAL BUS VOLUME CROSSING 60TH STREET SCREEN LINES, 5 TO 6 P.M. PEAK HOUR, OUTBOUND, 1987

60TH STREET SECTOR	EXPRESS BUS	LOCAL BUS	TOTAL
FDR DRIVE	2	0	2
YORK AVENUE	0	11	11
1ST AVENUE	8	32	40
3RD AVENUE	10	29	39
MADISON AVENUE	97	41	138
8TH AVENUE	8	11	19
BROADWAY	0	53	53
AMSTERDAM AVENUE	6	8	14
WEST END AVENUE	0	7	7
TOTAL	131	192	323

SOURCE: Hub-bound Travel
New York Metropolitan
Transportation Council

TABLE 4 PEAK-HOUR BUSES BY TYPE OF BUS, 44TH STREET–50TH STREET SCREEN LINE, 8 TO 9 A.M., 1986–1988

	EXPRESS	LOCAL	TOTAL
LOCATION (SB)			
2ND AVENUE	89	46	135 (78)
LEXINGTON AVENUE	38	21	59
5TH AVENUE	104	60	164
7TH AVENUE	11	52	63
BROADWAY	13	23	36
9TH AVENUE	-	7(1)	7
TOTAL	255	209	464 (78)
LOCATION (NB)			
1ST AVENUE	-	50(1)	50
3RD AVENUE	54	21	75 (11)
MADISON AVENUE	135	45	180
AVE OF THE AMERICAS	118	24	142
8TH AVENUE	-	50(1)	50
10TH AVENUE (1)	-	7	7
TOTAL	297	147	504 (11)

( ) DEADHEADING BUSES

SOURCE: NYCDOT - UNFRANCHISED BUS PLANNING STUDY, MARCH, 1988

(1) NYCTA 1988 LOCAL BUS VOLUMES

on Madison Avenue, Fifth Avenue, and Avenue of the Americas.

During the morning peak hour, there were 255 express and 209 local buses southbound and 297 express and 147 local buses northbound. Fifth Avenue carried 41 percent of the southbound express buses and 29 percent of the southbound local buses. Madison Avenue carried 45 percent of the northbound express buses but only 31 percent of the northbound local buses. Avenue of the Americas carried 40 percent of the northbound express buses.

During the evening peak hour, there were 161 express and 178 local buses southbound and 229 express and 216 local buses northbound. Fifth Avenue carried 85 percent of the southbound express buses but only 33 percent of the northbound local buses. Madison Avenue carried 59 percent of the northbound express buses but only 23 percent of the southbound local buses. Avenue of the Americas carried 34 percent of the northbound express buses but only 12 percent of the local buses.

Maiden Lane–Liberty Street

Table 6 gives the number of peak-hour buses crossing the Maiden Lane–Liberty Street screen line during the morning peak hour. The southbound express buses concentrated on Broadway, and the northbound express buses concentrated on Trinity Place/Church Street. FDR Drive, however, carried some southbound express buses.

TABLE 5 PEAK-HOUR BUSES BY TYPE OF BUS, 44TH STREET–50TH STREET SCREEN LINE, 5 TO 6 P.M., 1987–1989

	EXPRESS	LOCAL	TOTAL
LOCATION (SB)			
2ND AVENUE	4	20	24
LEXINGTON AVENUE	14(a)	44	58
5TH AVENUE	137	59	196
7TH AVENUE	-	13	13
BROADWAY	6(a)	36	43
9TH AVENUE	-	6	6
TOTAL	168	178	339
LOCATION (NB)			
1ST AVENUE	-	40	40
3RD AVENUE	10(a)	44	54
MADISON AVENUE	134	49	183
AVE OF THE AMERICAS	77	25	102
8TH AVENUE	8(a)	52	60
10TH AVENUE	-	6	6
TOTAL	229	216	445

NOTES & SOURCES
(a) - 1987 - NORTHBOUND ACROSS 60TH STREET CORDON
LOCAL BUSES - NYCTA 1988 SCHEDULES
EXPRESS BUSES - 1989 FIELD SURVEYS NYC DCP

TABLE 6 PEAK-HOUR BUSES CROSSING MAIDEN LANE–LIBERTY STREET SCREEN LINE BY TYPE OF BUS, 8 TO 9 A.M., 1986–1988

LOCATION	EXPRESS	LOCAL	TOTAL
SOUTHBOUND			
FDR DRIVE	37 (23)	0	37 (23)
SOUTH STREET	1	0	1
WATER STREET	36	7	43
BROADWAY	96 (13)	13	109 (13)
WEST STREET	57 (39)	1	58 (39)
TOTAL	227 (75)	21	248 (75)
NORTHBOUND			
FDR DRIVE	53	0	53
WATER STREET	11	7	18
TRINITY PLACE/ CHURCH STREET	143	21	164
WEST STREET	0	72	72
TOTAL	207	100	307

( ) DEADHEAD BUSES

SOURCE: UNFRANCHISED BUS PLANNING STUDY NYCDOT, MARCH, 1988

ANALYSIS OF CONGESTED CORRIDORS

Several bus corridors in Manhattan are critical in terms of bus volumes and speeds, including Fifth, Sixth, and Madison avenues in Midtown and Broadway and Church Street in Lower Manhattan. Each of these streets carries more than 100 buses in the peak hour, each is heavily used by express buses, and each has peak-hour bus speeds of less than 8 mph (usually 3 to 5 mph).

The maximum observed hourly bus volumes crossing selected screen lines in the congested corridors are summarized in Table 7. These flows are based primarily on the bus volume counts conducted during the past decade at the various cordon and screen lines. They show the highest volumes that were observed without regard to the year of observation.

- At the 60th Street screen line, a maximum volume of 223 buses was observed southbound on Fifth Avenue during the morning peak hour. During the evening peak hour, Madison Avenue carried a maximum volume of 206 buses northbound.
- At the 44th Street–50th Street screen line, a maximum volume of 196 southbound buses was observed on Fifth Av-

TABLE 7 MAXIMUM OBSERVED PEAK-HOUR BUS VOLUMES

SCREEN LINE AND AVENUE DIRECTION			NUMBER OF BUSES AM PEAK HOUR	PM PEAK HOUR
A.	60TH STREET			
	FIFTH AVENUE	SOUTHBOUND	146(223)	NA
	MADISON AVENUE	NORTHBOUND	NA	138(206)
B.	44TH/50TH STREET			
	FIFTH AVENUE	SOUTHBOUND	164	196
	MADISON AVENUE	NORTHBOUND	180	183
	AVENUE OF THE AMERICAS	NORTHBOUND	142	102
C.	MAIDEN LANE/LIBERTY STREET			
	BROADWAY	SOUTHBOUND	109	150
	TRINITY PLACE/ CHURCH STREET	NORTHBOUND	164	NA

Note: 1987-9 Volumes are shown. Maximum volumes between 1983 and 1989 are shown in parenthesis

NA - Not Applicable

enue, 183 northbound buses on Madison Avenue, and 142 northbound buses on Avenue of the Americas.

DEFINING LIMITS OF ACCEPTABLE BUS SERVICE

The next step was to estimate (*a*) how many additional peak-hour buses Manhattan CBD streets can accommodate and (*b*) how many additional buses can cross the Manhattan cordon when keyed to the ability of the Manhattan streets to accommodate them.

Capacity Factors

The maximum number of buses that can operate through a street system is determined by the capacity of the approach roadways and that of the points of maximum passenger boarding and discharge, whichever is less. In most cases, capacity is limited by the ability of buses to board and alight passengers at the busiest bus stops. This is true in the Manhattan CBD. Many crossings of the East and Hudson rivers can accommodate more buses (though cars would be displaced); the choke points for buses occur along a few arteries in Midtown and Lower Manhattan.

The maximum number of buses that can operate on any street depends on the characteristics of the street (e.g., number of travel lanes, traffic signal timing, traffic regulations, and availability of bus-only lanes), the nature of adjacent land use (e.g., residential or commercial); the patterns of passenger boarding and alighting, and the fare collection methods used.

More specifically, the capacity of a bus lane in buses per hour depends on the following:

- Green/cycle ratio,
- Dwell times at major stops,
- Specified spacing (in seconds) between buses,
- Number of effective berths, and
- Allowance for bunching of vehicles and overloading or failure of the stop.

Dwell times depend on the door configuration, fare structure, and number of boarding and alighting passengers.

The availability of bus priority lanes significantly increases the number of buses that a street can accommodate. Curb space and the availability of bus-only lanes are far more important determinants of street capacity than is street width. Ideally, the number of buses operating on any street should be less than the maximum number possible.

The 1985 *Highway Capacity Manual* (*1*, Table 12-11) suggests the following guidelines for the maximum number of buses per lane per hour. The guidelines are based on the assumption that buses operate in an exclusive lane and stop to discharge or receive passengers.

Level of Service	*Arterial Street*	*CBD Street*
D	81–105	61–80
E (maximum)	106–135	81–100

Suggested Guidelines

Suggested guidelines for acceptable bus service on Manhattan streets were developed on the basis of observations of bus operations and volume and speed data. The guidelines, given in Table 8, adapt the *Highway Capacity Manual* criteria to Manhattan. The values set forth in the manual were modified to reflect Manhattan operating conditions and experiences. Table 8 shows both the maximum number of buses and the acceptable (desired) limit (about 90 percent of the maximum). The capacities are less in the evening peak hour than in the morning because of the longer passenger service times associated with boarding passengers.

The dual bus lane operations on Madison and Fifth avenues have maximum capacities of about 225 and 200 buses during the morning and evening peak hours, respectively. The ac-

TABLE 8 SUGGESTED LIMITS FOR STREETS AND AVENUES (MIDTOWN AREA)

AVENUE OR STREET	ESTIMATED MAXIMUM BUSES/HOUR CAPACITY	DESIRED LIMIT
FIFTH AVE-MADISON AVE (1) (DUAL BUS LANES)	200 (AM) 180 (PM)	180 (AM) 150 (PM)
SINGLE BUS LANE (WITH PASSING OPPORTUNITY - WIDE AVENUES)	120 (AM) 90 (PM)	90 (AM) 80 (PM)
SINGLE BUS LANE (WITH NO PASSING OPPORTUNITY - I.E. NARROW AVENUES-CROSS STREETS)	80 (AM) 70 (PM)	70 (AM) 60 (PM)
BUSES IN CURB LANE WITH MIXED TRAFFIC	70 (AM) 60 (PM)	60 (AM) 50 (PM)

(1) 5TH AVE OPERATES LARGELY AS A DE FACTO DUAL BUS LANE

ceptable (or desired) levels of bus flow on these streets (limits) are 180 and 150 buses per hour during the morning and evening peak hour, respectively.

On Manhattan avenues (north-south streets) having a single bus lane, acceptable bus flow volumes of 90 buses per hour during the morning peak hour and 80 buses per hour during the evening peak hour appear reasonable.

Volume-Capacity Comparisons

Table 9 indicates that the actual number of buses on most Midtown avenues during the peak hour is less than the desired limit. The principal exceptions are Fifth, Madison, and Sixth avenues. However, if a dual bus lane were provided on Sixth Avenue, the peak flows would fall below the desired limits.

Table 10 indicates that bus flows on both Church Street and Broadway in Lower Manhattan approximate the desired limits for these streets.

The tables have several implications.

1. Buses on Madison and Fifth avenues operate at capacity with dual bus lanes. Therefore, no additional buses making passenger stops should be allowed on these streets during peak hours.
2. Sixth Avenue can accommodate additional buses if dual bus lanes are provided and right turns are prohibited during peak hours.
3. Lexington, Second, and Third avenues can accommodate more peak-hour buses.
4. Church Street and Broadway in Lower Manhattan appear to be unable to carry more buses in rush hours. Some gains might be achieved by limiting the number of cars on Broadway in the evening rush or providing dual bus lanes, and by running more buses nonstop on Church Street through Lower Manhattan.

Increasing Buses in the Manhattan CBD

The number of additional buses that could be effectively accommodated in the Manhattan CBD over the existing streets and with operational changes was estimated.

It was assumed that no changes would be made in street directions, but that certain operational changes would be made to accommodate additional express buses. It was also assumed that buses would receive and discharge passengers in the heart of Midtown. Therefore, the capacity reserves on the peripheral avenues (First, Second, Eighth, and Ninth) were not considered. These streets could accommodate additional buses, but they are too far from most passengers' destinations and, therefore, would have limited passenger attraction.

Table 11 gives the additional express buses that could be accommodated in the Manhattan CBD with certain operational changes and the likely orientation of the additional buses.

- Lexington Avenue, in conjunction with dual bus lanes on Sixth Avenue, could allow 30 more peak-hour buses each way. The buses probably would run to or from the Bronx.
- A pair of bus-taxi streets (53rd and 54th streets) could carry 60 more peak-hour buses each way. They could serve Queens and use Second and Third avenues for access to the Midtown Tunnel and Queensboro Bridge.
- A new Lower Manhattan bus terminal could serve at least 100 peak-hour buses from Brooklyn, Staten Island, and New Jersey.

Additional local buses could be accommodated on all north-south avenues except Lexington, Fifth, Sixth, and Madison avenues. The number of added peak-hour buses would range from about 25 on First Avenue to more than 70 on Tenth Avenue.

The 42nd Street transitway is planned to be built in two stages. The first stage will consist of dual eastbound bus lanes

TABLE 9 BUS VOLUME CAPACITY COMPARISONS, MIDTOWN (ABOUT 50TH STREET—ALL BUSES)

	OBSERVED PEAK BUSES/HOUR	DESIRED LIMIT	RESERVE
	AM PEAK HOUR		
NORTHBOUND			
1ST AVE	50	90	40
3RD AVE	64	90	26
MADISON AVE	180	180	0
6TH AVE	142	90{a} [180]	-52 [38]
8TH AVE	50	90	40
10TH AVE	7	90	83
SOUTHBOUND			
2ND AVE	57	90	33
LEXINGTON	59	90	31
5TH AVE	164	180{e}	16
BROADWAY	36	90{d}	44
7TH AVE	63	90{d}	83
9TH AVE	7	90{d}	83
	PM PEAK HOUR		
NORTHBOUND			
1ST AVE	40	80	40
3RD AVE	54	80	26
MADISON AVE	183	150{b}	-33
6TH AVE	102	80{c} [150]	-22 [48]
8TH AVE	60	80	20
10TH AVE	6	80	74
SOUTHBOUND			
2ND AVE	24	80	46
LEXINGTON	58	80	32
5TH AVE	196	150{a}	-46
BROADWAY	42	80{d}	38
7TH AVE	13	80{d}	77
9TH AVE	6	80{d}	74

NOTES: {a} Maximum Capacity 120
{b} Maximum Capacity 180-200
{c} Maximum Capacity 90
{d} Assumes buses pre-empt curb lane
{e} Maximum Capacity 200-225

Note: When volumes exceed capacity, this implies recurrent "spillover" of buses into adjacent lanes.

[Figures in brackets show likely capacity gains from dual bus lane on 6th Ave (Avenue of the Americas)]

TABLE 10 BUS VOLUME-CAPACITY COMPARISONS, CHURCH STREET-BROADWAY, LOWER MANHATTAN, A.M.

	EXISTING PEAK HOUR BUSES	DESIRED LIMIT	RESERVE
CHURCH STREET	164	180(a)	16
BROADWAY	150	150(a)	0

(a) Estimated.

TABLE 11 ESTIMATED ADDITIONAL EXPRESS BUSES THAT COULD BE ACCOMMODATED IN CBD

		ADDITIONAL BUSES		
STREET	OPERATIONAL CHANGE	AM PEAK HOUR	PM PEAK HOUR	LIKELY ORIENTATION
LEXINGTON AVENUE	REROUTING	30	30	BRONX
SIXTH AVENUE	DUAL BUS LANES	30	30	
54TH STREET	ONE-WAY BUS STREETS	60	60	QUEENS
53RD STREET	BUSES RUN NON-STOP VIA 3RD-1ST AVE	60	60	
	TOTAL, MIDTOWN	180	180	
LOWER MANHATTAN TERMINAL	TOTAL, DOWNTOWN	100	100	BROOKLYN STATEN ISLAND NEW JERSEY
	TWO-WAY TOTAL	280	280	
	ONE-WAY TOTAL	190	190	

Source: Estimated

and a single westbound bus lane. These lanes largely would be preempted by the existing local and airport buses using 42nd Street. However, some reserve would be available. When the two-way transitway is built along the south side of 42nd Street (the second stage), it may be possible to operate more buses. The number of additional buses will depend on policy decisions about light rail versus bus operations.

Setting Limits on Gateways

The possibility of setting limits on the number of express buses entering Manhattan from outer boroughs and New Jersey was suggested in a study (*2*). Such limits do not appear necessary now because (*a*) the number of express buses entering Manhattan has declined in recent years; (*b*) bus flow is limited by the capacity of the major passenger boarding points within the business district, not at the gateways to Manhattan; and (*c*) enforcement would be difficult and probably would have to be done through the franchising process.

Moreover, new legislation would be required to establish the ceilings. It would be especially difficult to limit the number of buses coming from New Jersey, because these buses are certified to operate by the Interstate Commerce Commission, not by New York City.

Roads entering Manhattan operate at capacity. The increased bus volumes would displace cars. Whereas the automobile peak period might be lengthened, passenger productivity (i.e., passengers carried per lane per hour) would increase if more buses were in the traffic stream.

Because buses are more efficient users of street space than cars, car restrictions should take precedence over bus restrictions. Therefore, placing limits on the gateways to Manhattan becomes meaningful only if express bus volumes rise or as part of the city's forthcoming strategies to reduce bus-induced congestion and improve air quality.

Substantial increases in the number of express buses entering Manhattan in peak periods could be accommodated if street and terminal space in Manhattan were adequate. Provision of bus-only lanes through the Brooklyn-Battery and Queens Midtown tunnels could enable 500 or more buses per hour to enter Manhattan, compared with less than 200 per hour today. However, the existing streets and terminal facilities could not handle these flows. Consequently, the number of additional peak-hour buses entering Manhattan should be compatible with the number that can be accommodated by the street system. An initial formulation of such limits by gateway is given in Table 12.

Table 12 indicates that the existing street system limits the number of buses entering Manhattan to 1,570. With operational improvements, this number could increase to 1,760. (The maximum observed volume in 1985 was 1,553.) A limit of 1,330 buses leaving Manhattan in the evening peak hour is indicated. With operational improvements, this could increase to 1,490. (The maximum observed volume in 1985 was 1,318.)

Setting Site-Specific Limits

The number of buses that any avenue can carry depends on the capacity and use of the key bus stops along the avenue and the stopping pattern of buses. The capacity of a stop depends on the number of loading positions and the bus dwell times. The bus dwell times, in turn, depend on the number of alighting and boarding passengers, method of fare collection, and bus door configuration.

Thus, a more desirable approach is to identify proposed stopping patterns and to determine whether existing stops

TABLE 12 SUGGESTED LIMITS FOR EXPRESS BUSES BY SECTOR, KEYED TO CAPACITIES OF EXISTING STREETS

A. AM PEAK HOUR - INBOUND

SECTOR	MAXIMUM OBSERVED VOLUME	SUGGESTED LIMIT: EXISTING STREETS	SUGGESTED LIMIT: OPERATIONAL IMPROVEMENTS
60TH STREET	228	230	260 (1)
BROOKLYN	205	210	260 (2)
QUEENS	216	220	280 (3)
SUBTOTAL	649	660	800
NEW JERSEY	904	910	960 (4)
TOTAL	1553	1570	1760

B. PM PEAK HOUR - OUTBOUND

SECTOR	MAXIMUM OBSERVED VOLUME	SUGGESTED LIMIT: EXISTING STREETS	SUGGESTED LIMIT: OPERATIONAL IMPROVEMENTS
60TH STREET	199	200	230 (1)
BROOKLYN	142	150	200 (3)
QUEENS	140	140	170 (2)
SUBTOTAL	481	490	600
NEW JERSEY	837	840	890 (3)
TOTAL	1318	1330	1490

NOTES: (1) Assumes Dual Bus Lanes - 6th Ave
(3) Assumes 53-54th Bus-Taxi Streets
(2) Assumes Battery Garage Bus Terminal

have the capacity to serve more buses. NYC DCP is pursuing this approach in reviewing new bus franchise applications. Pilot analyses—applying *Highway Capacity Manual* formulas—indicated that key bus stops along Madison and Fifth avenues operate at or near capacity during the evening peak period, depending on the acceptable probability of congestion. The analyses confirmed the desirability of not adding more express bus routes to these avenues (*3*).

Improving Operations

Operations and capacities can be improved in several ways.

1. Enforcement of bus lanes should be intensified. This is a productive use of resources in terms of the people benefited.
2. Fare collection practices should be modified. Widespread use of passes, express bus tokens, automatic fare cards, and fare boxes that accept dollar bills would reduce dwell times. A "pay as you exit" procedure on outbound trips would also reduce dwell times in the CBD.
3. Electronic fare boxes should be provided on all buses.
4. Articulated (or double-decked) buses should be considered for some of the longer expressway runs, such as the TA service to Staten Island, because they can carry 25 to 35 percent more people per hour than conventional buses.
5. Providing better layover areas in Midtown would reduce deadhead bus flows.

IMPLICATIONS AND DIRECTIONS

The following directions emerge from the analyses of express bus operations in the Manhattan CBD.

1. Manhattan's local buses serve a market different from that served by parallel subway lines. Passenger trips are short (median 1.0 to 1.2 mi) and are not easily transferable to subway. Thus, it is not practical to remove local buses from key avenues to allow more space for express buses.
2. Express buses constitute the bulk of the bus volumes entering the Manhattan CBD and on Manhattan avenues. They are concentrated on Fifth, Madison, and Sixth avenues in Midtown, and on Broadway and Church Street in Lower Manhattan. These avenues penetrate the major employment concentrations. Eight of every 10 Midtown-destined bus riders have destinations between Third and Eighth avenues. Although some express buses may be diverted to peripheral

streets, most bus companies want to run buses on Fifth, Sixth, and Madison avenues, because these streets serve areas where most riders want to go.

3. It is not desirable to set limits on the number of express buses that can enter or leave the Manhattan CBD during peak hours. Setting limits for bus flows at gateways to Manhattan would become appropriate only as part of NYCDOT's overall Manhattan congestion-reduction program or if express bus volumes rise substantially. The key issue is one of accommodating buses at major boarding points rather than at gateways. Bus flows are critical in the Manhattan CBD, where heavy passenger boarding and alighting take place, not at the gateways. (The exception is Fifth Avenue north of 57th Street in the morning, where buses are limited to a single lane.) In addition, the number of express buses entering or leaving the Manhattan CBD has declined in the last few years, enforcement of such a ceiling could prove difficult, and legal problems could result from setting a ceiling.

4. There is little, if any, space for additional buses in the Manhattan CBD during peak hours on Madison, Fifth, and Sixth avenues in Midtown, and along Broadway and Church Street in Lower Manhattan.

5. The best way to assess the ability of a street to carry more buses is to evaluate the capacity and use of each stop and to determine whether existing stops can serve additional buses. Key questions to be addressed on a site-specific basis are the following: Where will new express bus routes run? Where will they receive and discharge passengers? Is there enough curb-loading space at specific stops to handle the additional buses? Pilot analyses indicated that key express bus stops along Fifth and Madison avenues were operating at or near capacity. Bus lanes along Broadway and Church Street in downtown Manhattan also operate at capacity.

6. Intensified enforcement, improved fare collection practices, widespread use of electronic fare boxes, articulated bus operations, and better layover practices could improve bus flows on Manhattan streets and avenues.

Analysis of potential markets indicates relatively limited opportunities for additional express service. Thus, major growth in express buses on Manhattan streets is not likely, and major restrictions on additional buses on Manhattan avenues are not essential at present.

Continued improvements in subway service, such as station modernization, new cars, and signal control changes, will affect future bus ridership, making the likelihood of dramatic increases in express buses on Manhattan streets even more remote. Finally, if a limit is to be implemented, perhaps cars rather than buses should be restricted.

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Evaluation of Automatic Passenger Counters: Validation, Sampling, and Statistical Inference

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Whereas automatic passenger counters (APCs) offer the potential for cost-effective data recovery, they introduce new complications in the data recovery process. Three issues associated with the use of APCs are addressed on the basis of the experience of the Tri-County Metropolitan Transportation District of Oregon. The first issue is validation, which concerns both recovery and accuracy of APC passenger data. The second concerns the design of a sampling methodology for APCs compatible with UMTA's Section 15 reporting requirements. Third is inferring system-level ridership from sample data in the presence of selective APC failures. APCs provided systematically accurate passenger counts. Given that APCs recover operating data for all bus trips making up a vehicle schedule, a cluster sampling method was developed. Selective data recovery failures can bias estimates of system-level ridership. When data recovery rates vary by bus type, route type, or time of day, inferences may over- or underrepresent total system ridership. In these circumstances, post hoc stratification of the sample is recommended. Several alternative corrections based on a priori knowledge of the mix of bus types and schedule characteristics in the system are presented.

Automatic passenger counters (APCs) offer potential benefits to transit operators in data acquisition, management, and utilization. Compared with manual collection, APCs are cost-effective for larger transit systems, and they provide better data turnaround and improved accuracy (*1*). They can also recover the large quantities of information required in analyzing transit performance at the disaggregate level, thus permitting greater sensitivity in service scheduling and planning.

Along with these potential gains, however, come several complications not found with manual data collection. First, only selected buses in the fleet—usually about 10 percent (*2*)—are equipped with APCs, and this results in a dependence on bus-specific assignments to selected routes rather than random assignment of surveyors. Even under the best of circumstances—where the requests for and actual assignments of APC buses are well coordinated—less flexibility exists in the data recovery process. Second, whereas APCs generally return more accurate data than manual counters, many of the data are screened out because of functional inconsistencies. Apart from the resulting need for larger sample sizes is the question of whether, following the screening of unusable data, the remaining information still constitutes a representative sample of bus trips for the system. If failure rates are systematically related to route or other operational-specific characteristics, a nonresponse type of bias might undermine the sample ridership statistics and, consequently, inferences of systemwide operating performance. Third, with manual data collection, surveyors are typically assigned to randomly selected bus trips. With APCs the unit of observation is the "train" or "block," which consists of all the scheduled service performed by a bus during an operating day. The bus trips of a train are not independent, and thus the sampling framework recommended by UMTA (*3*) cannot be used. As a result, an alternative methodology must be designed consistent with the APCs' operating features.

These issues are addressed in the coming sections. On the basis of information drawn from the recent performance of APCs used by the Tri-County Metropolitan Transportation District of Oregon (Tri-Met), data recovery is considered by analyzing the accuracy of the data generated by APCs and the sources of data recovery failures. Whether the set of trains from which data have been successfully recovered represents an equal probability sample is then determined. A sampling methodology is developed ensuring that the selection of bus trips (through the selection of trains) is both random and of sufficient size to comply with UMTA's Section 15 reporting requirements. Finally, a remedy for correcting sample statistics subject to bias from nonrandom data recovery failures is suggested.

EVALUATION OF APC PERFORMANCE

Data Recovery

Tri-Met's APC system uses infrared sensors located about waist high at the stairwells of the front and rear bus doors. An on-board microprocessor records passenger boardings and alightings, times, and distances. At the end of the day the recovered data are transferred to a microcomputer using an automated infrared transmitter that scans the buses from fixed stations at each of the agency's three garages. The system was manufactured by Red Pine Instruments of Denbigh, Ontario, and is installed on 50 of Tri-Met's 567 buses. Implementation of the APCs was initiated in 1982, and Tri-Met has relied on the system to provide data for UMTA Section 15 reporting since the 1986 fiscal year. APC-generated data are also used internally for route performance reporting and contribute to a lesser extent to scheduling and analysis.

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Software for validating and managing the APC data was developed in-house. Incoming data are assigned route and bus identification codes and are then aggregated to the bus trip level. A program checks the data for compatibility with various validation standards. Train or trip level data that fail to meet these standards are purged. At the train level, observations are deleted for the following reasons: (*a*) recorded distance differs from actual by more than 15 percent, (*b*) time between pullout and pull in differs by more than 30 min from the service schedule, or (*c*) total boardings and alightings differ by more than 10 percent.

Validation standards covering distances and pullout and pull-in times at the bus trip level are also applied. If several of the trips in a train are deleted, the remaining trips in that train are more thoroughly evaluated manually, which may result in purging the data for an entire train.

The sampling plan used by Tri-Met is organized around the five sign-up periods making up annual scheduled service. The objective of the plan is to sample the scheduled trips in each sign-up uniformly. Execution of the sampling plan requires the involvement of several divisions. The scheduling division, using a selection program that assigns higher selection priorities to trains that have been undersampled previously, draws a sample of trains daily. The trains selected for sampling by the scheduling division are called "requests." Daily lists of requests are provided to the operations division, which is responsible for assigning an appropriate APC-equipped bus model to each of the trains requested. In practice, not all the trains from the daily list of requests are successfully assigned an APC bus, and sometimes APC buses are assigned to trains that were not requested. Thus the daily tally of assignments consists of a group of trains for which APC buses were both requested and assigned and a group of trains for which APC buses were assigned but not requested. Finally, the train assignments (both requested and unrequested) that return valid data are defined to represent the set of successfully sampled trains.

Information on the degree of success recently encountered by Tri-Met in recovering data with the APC system is presented in Table 1. Records from the first half of the April–June 1989 sign-up identify 1,589 requests, of which 1,089 (69 percent) were assigned APC buses. Another 325 trains that were not requested were assigned APC buses. Valid data were recovered from 286 of the trains that had been requested and from 82 unrequested trains. Thus data were recovered from 26 percent of all assignments.

Losses of data resulted from various causes, including exceeding time tolerances (7 percent of the total failures), distance tolerances (5 percent), discrepancies between boardings and alightings (7 percent), incorrect or missing assignment information in the train records (11 percent), recovered data that were unusable (8 percent), and failures due to bus or equipment malfunction (62 percent). The last category represents cases for which no data were returned by the APCs. Failures in this category include instances in which the APC unit accidentally reset, buses did not pull close enough to the transmitter to allow transfer of the data, the microprocessor's memory was filled and could not record more data, and data were not recorded because of equipment breakdown.

Of the 1,414 train assignments, 368, or 26 percent, returned valid data. This rate is considerably lower than what has been reported in other studies of APC performance (*1,4*). Generally, about 80 percent of all train assignments have been reported to return valid data. The reasons for this difference cannot be further explored because of the lack of more detailed information about the performance of other APC systems. Among the factors contributing to Tri-Met's low data recovery rate could be differences in screening tolerances used in validating the data, differences due to the mix of APC-equipped bus types in Tri-Met's fleet, and differences in APC technology. Given both the relatively small data recovery rate and the inclusion of unrequested trains, the question of nonresponse or sampling bias, or both, arises. It is therefore necessary to determine if the data losses were random or were systematically related to train-specific characteristics.

TABLE 1 BREAKDOWN OF APC DATA RECOVERY, APRIL 1989 SIGN-UP

	No.	%[1]
1. Trains Requested	1,589	100
2. Trains Assigned		
a. As requested	1,089	77
b. Unrequested	325	23
c. Total assignments	1,414	100
3. Data Recovered		
a. From requested trains	286	78
b. From unrequested trains	82	22
c. From all assigned trains	368	100
4. Data Recovery Failures, due to		
a. Time tolerances	71	7
b. Distance tolerances	56	5
c. On/off tolerances	71	7
d. Incorrect/missing assignment information	113	11
e. Unusable data	85	8
f. No data	650	62
g. All sources (a-f)	1,046	100

[1] The percentage figures pertain to the breakdowns within each numbered category.

Determinants of Successful Data Recovery

The September–November 1988 sign-up was selected for a regression analysis of factors related to successful data recovery. Tri-Met staff considered this sign-up typical in regard to APC performance and other operating and ridership characteristics. During the sign-up 588 trains provided daily weekday service. Valid data were recovered from 1,552 assignments (about 3.4 percent of total scheduled weekday service). The following model was specified to examine the effects of train-specific characteristics on successful data recovery:

$$SAMP = f(APC, REQ, ASG, AM, PM, G_1, G_2, ARTIC, ADB, B500, B300)$$

where

- SAMP = the number of assignments in each train that recovered valid data;
- APC = the number of available APC buses of the requested type at the garage from which each train assignment was made;
- REQ = the number of times each train was requested;
- ASG = the number of times each train was assigned;
- AM = 1 if the train provided only a.m. peak service, 0 otherwise;
- PM = 1 if the train provided only p.m. peak service, 0 otherwise;
- G_1 = 1 if the train was dispatched from Garage 1, 0 otherwise;
- G_2 = 1 if the train was dispatched from Garage 2, 0 otherwise;
- ARTIC = 1 if the train was an articulated bus model (Crown-Ikarus), 0 otherwise;
- ADB = 1 if the train was an ADB bus model (40-ft GMC RTS-II), 0 otherwise;
- B500 = 1 if the train was a B500 bus model (40-ft Flexible "Metro"), 0 otherwise; and
- B300 = 1 if the train was a B300 bus model (35-ft Flexible "New Look"), 0 otherwise.

The APC variable was included in the specification to account for differences in the number of APC buses of each relevant type at each garage. Data recovery is expected to improve when more buses are available for assignment. The number of requests was included to control for trains that were not successfully assigned because of operational or mechanical problems. Tri-Met's sampling software places a higher subsequent selection priority on trains that are requested but not assigned. A greater frequency of requests would thus be associated with trains that are not successfully recovering data. The number of assignments controls for variations in data recovery attributable to the relative frequency of train assignments; in other words, some trains may recover valid data more frequently because they are assigned more frequently. AM and PM were included because these trains are in service for a shorter time and should be more reliable in returning data successfully. They are also likely to have higher ridership per bus trip than "day" trains and thus could shift the sample statistics upward if they are overrepresented. The garage variables were included to check for differences in data recovery attributable to the performance of the system among Tri-Met's three garages. The variables G_1 and G_2 represent the operator's two satellite facilities. The four fleet type variables are included to determine whether variations in data recovery can be linked to the mix of bus types in the system.

Table 2 presents descriptive statistics and parameter estimates for the data recovery model. The R^2 of .62 and overall

TABLE 2 REGRESSION ESTIMATES OF THE DETERMINANTS OF TRAIN LEVEL DATA RECOVERY, SEPTEMBER 1988 SIGN-UP

Variable	Mean	St. Dev.	Coefficient	t-ratio
Constant	n.a.	n.a.	.26	1.76
APC	6.86	5.01	.169	4.67**
REQ	4.46	5.03	-.252	-10.81**
ASG	5.52	3.66	.235	7.09**
AM	.29	.45	.311	2.43*
PM	.30	.46	.782	6.10**
G_1	.31	.46	-.666	-4.20**
G_2	.32	.47	.861	6.16**
ARTIC	.15	.35	-.136	-.76
ADB	.15	.36	2.090	10.62**
B500	.09	.28	-.061	-.29
B300	.30	.46	1.285	8.48**

R^2 = .62

F = 86.14

n = 588

* Significant at the .01 level.

** Significant at the .0001 level.

F value of 86.14 indicate that the model provides a moderately strong fit of the data. The parameter estimates for APC, REQ, and ASG have the expected signs and are highly significant. AM peak trains returned 0.3 more observations per train than day trains, whereas the net increase for PM peak trains was about 0.8. Both are statistically significant and represent increases of approximately 10 and 30 percent over the data recovery rate for day trains.

Among the various bus types, the ADB and B300 models recovered 2.1 and 1.3 more sample observations per train than the "reference" bus type (B100/1000, which includes 40-ft AMGeneral and 40-ft Flexible "New Look" models). Garage 1 produced 0.67 fewer and Garage 2 produced 0.86 more observations per train in relation to the central garage. These differences are most likely due to breakdowns of the fixed-station transmitters at the garages, because assignments are proportionately distributed among the three garages. The transmitter at Garage 2, by implication, experienced fewer problems than the transmitters at the other two garages. Alternatively, some routes may be more likely to return valid data than others; a variation in the composition of route types by garage could affect relative data recovery rates.

Besides isolating various determinants of successful data recovery, the regression results point to possible sources of over- and underrepresentation of trains in the effective sampling scheme. Of particular concern are the AM and PM peak trains and two of the bus types. Significant differences in ridership characteristics among the trains in question can represent a source of bias in the overall sample estimates of ridership and other operating characteristics. This issue is addressed further in the section on sample inferences.

Measurement Accuracy

For the data that are successfully recovered by the APCs, another concern is the accuracy of the passenger counts. Automatic counters have been described as more accurate than manual data recovery, particularly for high-volume routes and routes with peak-period standing loads (*1*). The errors that have been observed with APCs indicate a tendency to undercount rather than overcount passenger activity, whereas boardings tend to be counted more accurately than alightings.

In a demonstration study of APCs equipped with infrared beams, the Washington Metropolitan Area Transit Authority conducted an accuracy test on a sample of more than 400 bus trips involving about 18,000 boardings and alightings (*5*). Total boardings recorded by the APCs equaled 99.7 percent of the manual counts, and recorded alightings equaled 98.4 percent of the manual counts. However, the circumstances of this evaluation were quite controlled, with a limited number of routes included in the survey. A field test in 1982 of five properties using APCs (Minneapolis–St. Paul, Columbus, Kalamazoo, Seattle, and Los Angeles) found slightly larger discrepancies between APC counts and recordings by manual checkers, although the differences were not statistically significant (*1*).

Previous research has thus consistently demonstrated that APC and manual passenger counts tend to correspond. The APC systems evaluated were relatively new, however. Tri-Met's APCs have been in service for nearly 7 years, and their low data recovery rate indicates that they have not been performing at the levels observed elsewhere. As a result, a statistical comparison of APC and manual passenger counts for Tri-Met's system was undertaken.

Forty-six APC buses were selected for the evaluation. The buses were assigned to a representative set of routes, and both manual and automatic counts of boardings and alightings were recovered for each stop. The number of stops per bus ranged from 44 to 148 and totaled 3,768 across all observations. A test of the mean difference between APC and manual counts of boardings and alightings per stop was conducted for each bus as well as for the overall sample. Table 3 gives the findings for the overall analysis and for those buses having significant differences between APC and manual counts. Across all buses and all stops, the average boardings per stop counted by the APC were 0.01 passenger higher than the manual count, and the number of alightings counted by the APCs averaged 0.01 passenger lower. Neither difference was statistically significant at the .05 level. Of the six instances in which the APC and manual boarding counts differed significantly, three involved overcounting and three involved undercounting. Of the five instances in which the APC and manual alighting counts differed, two involved overcounting by the APC. Three specific buses were associated with significant differences in both boardings and alightings.

TABLE 3 TESTS OF DIFFERENCES BETWEEN APC AND MANUAL COUNTS: OVERALL RESULTS AND CASES INVOLVING SIGNIFICANT DIFFERENCES

Boardings

Bus #	No. of Stops	APC - Manual	t - ratio
347	80	.25	2.78
350	142	.13	2.71
901	81	-.11	-2.58
731	62	-.35	-2.50
119	82	.09	2.16
1040	81	-.10	-2.04
All Buses	3,768	.01	.68

Alightings

731	62	-.52	-3.12
347	80	.15	2.80
119	82	-.12	-2.43
526	85	.09	2.19
900	138	-.07	-2.07
All Buses	3,768	-.01	-1.38

Because significant differences between APC and manual counts were found in only a few cases, and because there was no pattern of divergence, the APCs appear to provide systematically accurate counts. With 92 applications of the hypothesis test at the 95 percent confidence level, about five rejections of the null hypothesis due to Type I error (i.e., rejecting the null hypothesis of no difference when it should have been accepted) are expected. Moreover, an underlying assumption is that the manual counts are free of error, and this is likely to be violated in some cases. Finally, the data recovered by the APCs were not subjected to the normal screening process, which would have purged substantial portions of the data recovered from several buses (i.e., Buses 347 and 731).

SAMPLING WITH APCs

Two issues concerning sampling with APCs must be addressed. The first concerns the low data recovery rate when APCs are used and the fact that observations on some bus trips were assigned but not requested in the sampling methodology. This raises questions about the representativeness of the sample, which could fail from assignment or response bias.

The second issue concerns the sampling methodology itself. The sampling procedure recommended by UMTA (*3*) was essentially designed with manual data collection in mind, because it provides solely for independent random selection of bus trips. With APCs, bus trips are necessarily selected in blocks composing trains. Whereas trains can be selected in an independent and random fashion, the individual bus trips cannot. As a result, a specific methodology for APCs must be developed that ensures satisfaction of the UMTA precision standards and minimizes the number of bus trips required to be sampled.

Evaluation of the Recovered Sample

There are three possible threats to representativeness in the sampling of APC-equipped trains. First, the initial requests for train assignments may not be representative. Second, the actual assignments may not be representative if they do not fully correspond with the requests. Third, the trains from which data are ultimately recovered may not be representative, given the previously identified association between selected train characteristics and successful data recovery. The latter two possibilities are addressed by evaluating the September–November 1988 sign-up. Train requests are not evaluated because the selection procedure used by Tri-Met assigns a higher priority to trains that were previously requested but not assigned. Thus if requests were found to be unrepresentative, attributing the cause to problems associated with the request or the assignment process would be difficult.

A chi-square test was used to determine whether the systematic patterns of trains that were requested and assigned, assigned, and successfully sampled represented an equal probability sample. The results of the tests are given in Table 4. The null hypothesis that the observations constituted an equal probability sample is rejected at the .05 level for trains that were requested and assigned and for total assignments. It could not be rejected, however, for the trains that successfully generated data. This finding is in part attributable to the smaller number of successful assignments compared with total assignments, which correspondingly reduces the comparative intertrain variance and the calculated chi-square value. It also indicates why the chi-square is considered to be a relatively weak test statistic (i.e., it is sensitive to the scale of measurement).

An APC Sampling Methodology

The objective in designing a sampling methodology for APCs is to identify the minimum number of randomly selected trains required to generate passenger information at the bus trip level that will satisfy UMTA's precision standard of ± 10 percent at the 95 percent level of confidence. The methodology must account for correlation among bus trips within trains, and it should set the sample size large enough to reflect the anticipated data recovery rate.

The special features associated with the APC data recovery process are compatible with a multistage cluster sampling method (*6*). The first stage in this methodology would consist of a random selection of trains, and the second stage would then be defined by the 100 percent "clusters" of bus trips composing the selected trains. Variations in cluster sizes would also be accommodated, because the number of bus trips can vary by train. The methodology would be designed for implementation at the train level, consistent with data recovery using APCs, yet ensuring that the sample statistics satisfy trip level precision requirements.

Cluster sampling has also been proposed for data collection by ride checkers (*7*). For many transit systems, run pieces (usually about 4 hr of service) represent a more convenient sampling unit than bus trips. Thus, whereas cluster sampling may be a necessity for data collection with APCs, it may also be a more cost-effective approach for other modes of data collection.

The determination of the required sample size for cluster sampling follows from the convention for simple random sampling, with modification to account for the trip-clustering effect. The sample size is first determined at the bus trip level and then converted to the train level on the basis of the observed average number of bus trips per train. In the presentation below, the sample size is determined for estimating passenger miles, because the relative variance of passenger miles tends to be larger than that of other operating data. The minimum number of bus trips to be sampled, in conformance with the UMTA Section 15 standards, is

$$n_c = [(1.96S_c)/(0.1M)]^2 \qquad (1)$$

where

n_c = the number of bus trips required in a multistage cluster sample,

S_c = the standard deviation of passenger miles per bus trip for a multistage cluster sample,

TABLE 4 CHI-SQUARE RESULTS FOR TRAINS IN THE SEPTEMBER 1988 SIGN-UP

	Requested/Assigned	All Assignments	Recovered Data
Mean observations per train	3.1	5.5	2.6
Calculated chi-square value	2,236.0	1,147.0	710.0
Critical value, .05 level	720.0	720.0	720.0
Number of trains	588.0	588.0	588.0

1.96 = the critical z value at the .025 level, and
M = the mean passenger miles per bus trip.

Equation 1 is equivalent to the arrangement used to determine the required number of observations for a simple random sample, except for the cluster sample standard deviation term, which accounts for the interdependence of bus trips within trains and the variation in the number of bus trips per train. The standard deviation for a simple random sample need not be elaborated, but its counterpart for a multistage cluster sample warrants presentation. This standard deviation is defined as follows:

$$S_c = [1/(n - 1) \cdot \sum_i n_i \cdot (M_i - M)^2]^{0.5} \quad (2)$$

where

n_i = the number of bus trips in Train i,
M_i = the mean passenger miles per bus trip for Train i, and
M = the mean passenger miles per bus trip across all bus trips.

Sample statistics from previously collected data can be used to derive the required sample size. Using Tri-Met's September–November 1988 sign-up as an example, the overall mean passenger miles per bus trip is 8,481 and the multistage cluster sample standard deviation is 19,159. The minimum required sample size for the sign-up in the example is thus

$$n_c = [(1.96 \cdot 19{,}159)/(0.1 \cdot 8{,}481)]^2 \quad (3)$$

or 1,961 bus trips.

The sample size derived above represents 14 percent of the 13,955 trip observations actually recovered during the September–November 1988 sign-up. By using the cluster-sampling framework, it was found that the sample produced precision of ±3.7 percent at the 95 percent level of confidence.

To achieve the required sample size, the data recovery rate should also be taken into account. Table 1 indicates that 26 percent of all assignments return usable data. This suggests that to achieve the necessary number of valid observations, 7,542 trip assignments (2.3 percent of all scheduled trips) would have to be made. This number of assignments is probably excessive, because an improved data recovery rate from smaller-sized samples (as indicated by the APC coefficient in the regression model) is expected.

Because trains are the unit of assignment with APCs, it is necessary to translate sample size requirements from bus trips to this unit. From the sign-up in the example, an average of 8.98 bus trips per train is found. Thus a minimum sample size of 218 trains is needed for the sign-up, which translates to 838 train assignments when the data recovery rate is accounted for.

The determination of the required sample size on an annual basis is a straightforward extension of the sign-up-level example presented above, with the key parameters in the sample size equation drawn from annual statistics.

Finally, because of the influence of the clustering effect on the required sample size, economic evaluation of APC performance in relation to manual data recovery should not be based on straightforward comparisons of costs per observation. The APC approach requires more observations to achieve the same level of precision as the manual approach, and this should be taken into account in assessing its relative merits. For example, under the assumption of simple random sampling, the minimum sample size for the September–November 1988 sign-up was determined to be 456 bus trips. The "design effect" (6,p.103) on the sample size resulting from recovering data with APCs rather than manually is 4.30. In other words, an APC sample would need to be more than four times as large as a simple random sample to achieve the same level of precision.

SAMPLE INFERENCES

The low data recovery rate experienced by Tri-Met with its APCs and the results of the statistical analysis of the determinants of successful data recovery indicate that the threat of sampling bias should be a concern for transit operators who use this technology. In Tri-Met's experience, the threats to randomness in sampling have been multifaceted and associated with both technical and procedural factors. In regard to procedural aspects of sampling, successful APC implementation mainly requires effective coordination among schedulers, bus dispatchers, and drivers. Hardware malfunctions involving APCs, attributable to the APC equipment itself or traceable to the buses, pose additional complications not found in manual data collection. Accounting for these factors in the sampling methodology would hardly be worthwhile because of their complexity and the likelihood that their effects are not constant over time. This suggests an alternative involving poststratification of the sample data as insurance against generating biased estimates of system performance.

The choice of stratification factors is the primary issue in reconciling APC data subject to sampling bias. The choice is essentially dictated by two considerations. First, over- and underrepresentation of various basic operating characteristics in the recovered sample should be accounted for. Second, among those operating factors identified as being over- or underrepresented, the subset exhibiting significant differences in ridership and representing nontrivial shares of the underlying population should be retained as stratification factors.

Several candidates for poststratification factors can be identified from the regression results reported earlier. They include the AM and PM peak variables (or, more generally, time-of-service stratification), which were associated with higher data recovery rates, and the bus type variables, which showed higher data recovery rates for two bus models. By stratifying these variables, a correction of the system ridership estimate, accounting for sampling bias, is obtained as follows:

$$R' = \sum_i t_i \cdot M_i \quad (4)$$

where

R' = the corrected total ridership estimate,
t_i = the total number of scheduled bus trips associated with Stratification Category i, and
M_i = the mean ridership value in Stratification Category i calculated from the sample observations.

Equation 4 pertains to an individual stratification factor. An extension to the joint application of two factors would be obtained as follows:

$$R' = \sum_i \sum_j t_{ij} \cdot M_{ij} \quad (5)$$

Poststratification corrections involving time-of-day and bus type factors were applied to the sample data from the September–November 1988 sign-up (see Table 5). A benchmark value of 159,937 average weekday boarding rides was obtained by multiplying the overall sample mean by the total number of scheduled trips. The benchmark total is the estimate that would be obtained using the procedure recommended in the UMTA guidelines, which assumes that the underlying sample of bus trips is random. In contrast with this value, poststratification by bus type resulted in an estimate of 158,199 boarding riders per weekday (1.1 percent lower), and poststratification by time of day produced an estimate of 157,864 (1.3 percent lower). Thus stratification by bus type and time of day had virtually no effect on the ridership estimate. Table 5 indicates that the bus types that were oversampled in the sign-up are little different from the overall sample in terms of the average boarding rides per trip. Had the articulated buses been over- or undersampled, the difference in estimated ridership would have been more noticeable. With the AM and PM peak corrections it is seen that because of their relatively higher ridership, the benchmark ridership estimate was overstated owing to the overrepresentation of these trips. The magnitude of the overestimate was muted, however, by the small ridership differential between peak and off-peak periods.

The application of poststratification corrections to the example above did not yield remarkable differences in estimated ridership. Because it had been previously established that the underlying data represented an equal probability sample, these results should not be surprising. Rather, the corrections offer a way to ensure that estimates of ridership are unbiased when the underlying sample data are not representative.

The relatively low data recovery rate for APCs, among other threats to randomness, indicates that a poststratification procedure ought to be included in the system software package and applied to inferencing as a matter of course. The specifics of stratification factors will be determined by the experience of transit operators in implementing APC sampling plans. Variations in APC hardware and software, fleet mix and type, general ridership and scheduling characteristics, and coordination among personnel preclude the development of standardized correction procedures. For those operators who have already implemented APC systems, an analysis of

TABLE 5 POSTSTRATIFICATION ESTIMATES OF AVERAGE WEEKDAY BOARDING RIDERS: SEPTEMBER–NOVEMBER 1988 SIGN-UP

Stratified by Bus Type

Bus Type	Average "ons"/trip	Scheduled Trips	Estimated Boardings
B100/1000	28	1,883	52,724
B300	19	1,802	34,238
ARTIC	40	608	24,320
ADB	24	1,083	25,992
B500	27	775	20,925
			158,199

Stratified by Time-of-Day

AM Peak*	27	911	24,597
Midday	28	3,146	88,088
PM Peak**	22	1,967	43,274
Other	15	127	1,905
			157,864

* The AM Peak period includes all trips initiated between 6:00 and 8:00 AM.

** The PM Peak period includes all trips initiated between 4:00 and 6:00 PM.

previously recovered sample data along the lines reported can identify the types of operating characteristics associated with differential data recovery rates.

CONCLUSIONS

Tri-Met's reliance on APCs to provide transit operating data has introduced procedural complexities and a certain rigidity not found with manual data collection. Among the concerns were the underlying precision, accuracy, and representativeness of the sample data. In the light of those concerns, methodologies covering sampling and inference that provide a determination of the sample size required to meet a given precision standard, as well as a means of reconciling unrepresentative sample data, have been developed. The accuracy of APCs with respect to passenger counts has also been verified.

Another area of concern is the low data recovery rate. Besides being a potential source of sampling bias, the low recovery rate necessitates more train assignments to achieve the required sample size. More than 45 percent of the assigned trains returned with no data, indicating a need for further evaluating the design, installation, and maintenance of the APCs. Contributions toward improvement in the recovery rate from the remaining sources of data failure, which collectively affect 28 percent of all train assignments, are probably not as likely as are improvements in the basic operation of the APC units. Thus Tri-Met's attention has been directed toward the latter objective.

Whether the costs and complications associated with APCs are outweighed by the estimated benefits of the technology has not been considered. The analysis has not been extended to the route level, where APCs provide the only practical means of comprehensive data recovery and thus offer substantial potential benefits. The scope of the evaluation would have to be extended to these elements, along with data management issues, to achieve a comprehensive assessment of the relative merits of APCs.

APCs have been found to be cost-effective compared with manual data recovery (*1*), although such analysis should account for differentials in sample sizes required to meet a given level of precision. The benefits of more rapid data turnaround with APCs are difficult to quantify, but on the basis of Tri-Met's experience the gains have not been substantial. This is due to Tri-Met's use of APCs primarily for UMTA Section 15 reporting, for which rapid data turnaround is not necessary.

Tri-Met also uses the data recovered by APCs to construct route performance reports for each of the five sign-up periods making up annual service, but questions about the underlying precision of ridership estimates at the route level have precluded a more prominent contribution of APC data to route analysis and scheduling. In an analysis of 32 routes (representing about 20 percent of Tri-Met's system), an average route level precision for mean boarding riders of ± 58 percent at the 95 percent level of confidence was found (*8*). This range is clearly too wide for route planning. To achieve route level precision comparable with what is required by UMTA at the system level would entail more than a 40-fold increase in sample size. Samples of this size can conceivably be recovered with APCs (which can be regarded as one of their potential benefits), but problems associated with coordination in executing the associated sampling plan would be considerable.

Assuming that difficulties associated with sampling and data recovery at the route level can be overcome, a more refined set of validation standards—targeted at the stop or route segment rather than the trip level—would be needed. This would require the development of detailed base level information on times and distances for the route network, which presently does not exist, against which the APC data could be validated. The data recovery rate would be expected to decline with more strictly defined validation standards applied to the present data recovery process. As a result, Tri-Met has considered acquiring an automatic vehicle locating system to supplement the APCs. The accuracy of the recorded APC data on times and distance would also need to be verified in a manner consistent with the approach used to test the validity of passenger counts.

Implementation of a comprehensive route level data recovery program thus faces a number of challenges. As an alternative to comprehensive data recovery, Tri-Met has been considering targeted applications of APCs. For example, one possible targeting strategy would be to reserve those APC buses not assigned to recover Section 15 data for intensive data recovery from routes where service changes are being considered. Another would be to select one of the five annual sign-ups for comprehensive sampling (i.e., combining Section 15 sampling efforts with route level sampling) and to convert the sample data to an annualized estimate of ridership. It was thought that fewer problems would be encountered for this alternative if large-scale sampling were undertaken in a single sign-up as opposed to an ongoing basis.

After nearly 7 years of operating experience, Tri-Met has yet to fully capitalize on the reported merits of APC technology. Application has been essentially limited to data collection for Section 15 reporting. Whereas the APCs may still be cost-effective for this purpose, their potential is greater.

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Methodology for Evaluating Urban Mass Transportation Act Section 16(b)(2) Applicants

MARC ADELMAN AND KEVAN DANKER

The methodology used to evaluate Virginia's applicants for capital grants for transportation aid through the Urban Mass Transportation Act's Section 16(b)(2) program is summarized. Eligible applicants include private nonprofit organizations that support program objectives of various state agencies. The previous use of essay questions to assess applicants' proposals produced inconsistent scoring results. Numerical scales of measurement were applied to a fixed-alternative and open-ended questionnaire in February 1990 to allow consistent comparisons of information and to provide consistent scoring assignments for all applicants. Specific variables were assigned different weighted values to gauge agencies of large and small fleet size by similar quality control standards. Various electronic spreadsheet functions were used to quantify and rank data. The relative significance of these measurement techniques to the evaluation process and their influence on future funding policy are discussed. These methods meet the needs and desires of Virginia's Section 16(b)(2) Review Committee and may also be useful to administering agencies of other states.

Section 16(b)(2) of the Urban Mass Transportation Act of 1964 authorizes financial assistance to private nonprofit organizations for capital projects that transport elderly and disabled individuals. Federal regulations direct state agencies to determine program criteria and to select projects for funding from all populated areas. Like other federal transportation programs, such as the programs for transit under Sections 18 and 9 of the Urban Mass Transportation Act, the Section 16(b)(2) program is designed to assist agencies with the purchase of rolling stock and radio communications equipment. However, the broad eligibility requirements, which permit applicants with diverse transportation objectives and resources to be considered together for funding, distinguish the Section 16(b)(2) program from the transit grants programs. The conflicting characteristics of human service transportation programs challenge administering agencies to design an equitable and uniform evaluation process.

The Virginia Department of Transportation (VDOT) shares the responsibility for evaluating applicants with a committee of representatives from state human service departments. To evaluate applicants' funding needs in an impartial manner, the committee modified the procedures of the review process. An advisory review subcommittee represented by staff from the Virginia Department of Health and VDOT was charged with revising the application format. Changes to the structure of the evaluation process included replacing general, essay questions with fixed-alternative and open-ended questions and substituting subjective scoring assignments with numerical measurement techniques. These modifications were made to eliminate bias caused by differences in agencies' writing styles, program goals, and client groups.

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OUTLINE OF METHODOLOGY

The previous use of essay questions to collect program data generated inconsistent responses from applicants. Grant writers applied different terms to describe service outputs and submitted various types of documentation to support their responses. Evaluations of essay replies by advisory review committee members yielded erratic scores for all applicants.

To allow consistent comparisons of information, a structured questionnaire was designed using clearly defined data classifications to limit the variety of possible responses and to standardize the data received. In addition, certain variables were compared as ratios to uniformly assess data provided by organizations with different fleet sizes.

The variables selected to measure applicants' proposals were grouped into the following criteria: operations procedures, maintenance procedures, coordination practices, service need characteristics, the proposed project's influence on fleet age and ridership, and Section 16(b)(2) funding history. Criterion weights were designated in accordance with the current operating practices of grantees. Point values for individual criteria were determined by the influence of associated variables on operating conditions related to the availability of public transportation service. The selection and weighting of discretionary criteria considered safety, reliability, and need factors that supported program goals, as agreed to by the advisory review committee.

The selection of questions for each criterion evolved from discussions with private nonprofit organizations about their operation. Through this process, the clarity and reliability of proposed variables were pretested. Agencies were also surveyed to ascertain common operating characteristics. This information was used to apply realistic standards to evaluate all applicants and to analyze whether providers should be grouped together by fleet size for scoring purposes.

A primary objective of the advisory review committee was to apply measurement techniques that did not produce large scoring variances to the evaluation of proposals. Qualitative data were assessed by measuring responses to fixed-alternative questions and assigning point values to each possible answer. Measurements of quantitative data were completed by ranking responses to open-ended questions for all applicants and assigning specific point values on the basis of the mean and standard deviation of each sample. The Section 16(b)(2) program manager was delegated the responsibility of measuring all criteria by these techniques, excluding the coordination criterion.

Descriptions of applicants' coordination efforts to reduce service inefficiencies or expand service opportunities with other agencies were assessed by committee review. In previous reviews, committee scores relating to the coordination criterion differed greatly for each applicant. This discrepancy was reconciled by limiting applicant responses to a fixed number of alternative categories for coordination practices and assigning specific point values for each coordination classification.

Operations

Applicants are asked to provide information concerning issues related to operational procedures. Organizations identify the single most appropriate response to fixed-alternative questions on supervision levels, training and hiring practices, and sources of revenue. The focus of the operations criterion is to assess agencies' operating procedures relating to safety, financial stability, and service reliability. This criterion has a weight of 40 out of a possible 240 points.

Maintenance

The second part of the program questionnaire obtains information on the applicant's ability to provide proper vehicle maintenance procedures. Organizations identify the single most appropriate response to fixed-alternative questions, including supervision of maintenance schedules, preventive maintenance work completed in-house, and available resources to inspect and maintain equipment. The maintenance criterion has a weight of 30 points.

This criterion was weighted fewer points than others because applicants' use of different record-keeping procedures and their dependence on various vendors to perform all maintenance procedures prevented consistent comparisons of maintenance data.

The advisory review subcommittee was responsible for coding and assigning point values to fixed-alternative responses to operations and maintenance questions. Variables were given distinct values depending on their estimated influence on providing safe, reliable transportation service. Responses to questions that required support documentation were allocated fewer points because of the difficulty in verifying information.

Certain quality control variables, such as the level of operations supervision, were determined to be strongly related to an agency's fleet size. In this case, coded responses were assigned different weighted values to gauge applicants of large and small fleet size by similar standards. Specifically, a small agency was defined as an organization operating one to five vehicles, excluding spare vehicles. Large agencies include organizations operating six or more vehicles during regular service hours.

Only 5 of the 18 questions used to assess applicants by quality control standards were assigned different weighted values to adjust for fleet size differences.

Coordination Practices

The applicant's description of its cooperative planning efforts to reduce service inefficiencies or expand service opportunities with other organizations is significant because of this criterion's heavily weighted value. The coordination criterion is weighted 60 points.

Service Needs

This criterion measures applicants' operations by conditions that influence the use of equipment. Organizations indicate whether public transportation service is available in their service area, the average number of unduplicated clients transported each month, the distance traveled to a maintenance garage, and the average number of miles operated per month.

Agencies are awarded a fixed number of points on the basis of whether public transportation service is available in their service areas. A ranking of the number of miles traveled to a maintenance garage to complete major repairs is produced for all applicants. Rankings of data ratios are generated for the total number of clients transported per vehicle and total miles operated per vehicle. This criterion is weighted 50 points.

Proposed Project's Influence on Fleet Age and Ridership

This criterion assesses applicants' need for requested equipment on the basis of related fleet age, ridership, and service use characteristics. Applicants are asked to indicate whether the requested equipment will be used to maintain, expand, or initiate service and to indicate the model year and mileage of each vehicle in their fleet.

Agencies obtain larger point values by demonstrating that the purpose of the proposed project is to replace equipment that has exceeded its useful life. Scoring assignments are also determined by a ranking of applicants' ridership figures per the total of requested vehicles and base fleet vehicles less than 5 years old or with less than 100,000 accumulated miles. This criterion is weighted 40 points.

Prior Funding

This criterion is designed to assign points on the basis of the applicant's Section 16(b)(2) funding history to allow for an equitable distribution of grant awards. A total of 20 points is awarded to organizations that have not received funding within 2 years of their application date. Agencies that have received funding during this 2-year period but did not receive equipment each year obtain no points. Organizations that received funding for two consecutive years before their application date were assigned −20 points.

QUESTIONNAIRE DESIGN FOR OPERATIONS VARIABLES

Table 1 gives examples of questions related to the supervision of applicants' transportation programs. Questions 1 through 4 differentiate between management responsibilities and operational duties. Responses to Questions 1 and 2 were not assigned point values because the questions' broad scope makes inconsistent comparisons likely. By addressing general transportation issues first and progressively narrowing the focus of Questions 3 and 4 to operations procedures, the probability of obtaining reliable data increases.

The purpose of Question 3 is to indicate whether large agencies allow a driver to serve as supervisor of operations while operating a vehicle. Large agencies are penalized 5 points subject to confirmation that a driver divides his responsibilities between supervising operations and driving duties. The objective of Question 4 is to survey the number of hours devoted to supervising operations by large and small agencies. Scoring assignments are based on four categories

TABLE 1 EXAMPLES OF SCORING ASSIGNMENTS FOR OPERATIONS QUESTIONS

1. Who is ultimately responsible for developing policy and procedures for your agency's transportation program?

* = Not Scored

		LARGE AGENCIES	SMALL AGENCIES
Executive Director	___	*	*
Program Director	___	*	*
Assistant Director	___	*	*
Transportation Manager	___	*	*
Transp Coordinator	___	*	*
Administrative Asst.	___	*	*
Driver	___	*	*
Other (Please Specify	___		

2. How many hours per week does that person allocate towards managing your agency's transportation program?

* = Not Scored

		LARGE AGENCIES	SMALL AGENCIES
40 or more hours	___	*	*
30 to 39 hours	___	*	*
20 to 29 hours	___	*	*
less than 20 hours	___	*	*

3. Who is responsible for supervising day to day operational duties for your agency's transportation program?

		LARGE AGENCIES	SMALL AGENCIES
Executive Director	___	(0)	(0)
Program Director	___	(0)	(0)
Assistant Director	___	(0)	(0)
Transportation Manager	___	(0)	(0)
Transp Coordinator	___	(0)	(0)
Administrative Asst.	___	(0)	(0)
Driver	___	(-5)	(0)
Other (Please Specify	___		

4. How many hours per week does that person spend on supervising day to day operational duties?

		LARGE AGENCIES	SMALL AGENCIES
40 or more hours	___	(8)	(8)
30 to 39 hours	___	(4)	(6)
20 to 29 hours	___	(2)	(6)
less than 20 hours	___	(0)	(0)

6. What percent of your agency's total budget is provided through donations or contributions?

		LARGE AGENCIES	SMALL AGENCIES
20% or more	___	(0)	(0)
10% -19%	___	(2)	(2)
5% - 9%	___	(4)	(4)
1% - 4%	___	(6)	(6)
0%	___	(8)	(8)

10. What percent of your agency's drivers do not receive wages?

		LARGE AGENCIES	SMALL AGENCIES
50% or more	___	(0)	(2)
30% -49%	___	(2)	(4)
10% -29%	___	(2)	(4)
1% - 9%	___	(4)	(6)
0%	___	(8)	(8)

11. Does your agency require drivers to submit their motor vehicle record with their application prior to hiring?

		LARGE AGENCIES	SMALL AGENCIES
Yes	___	(2)	(2)
No	___	(0)	(0)

ranging from less than 20 to 40 or more hours of supervision.

The difference in scoring assignments for large and small agencies exists at the intermediate levels of supervision. Small agencies that supervise operations between 20 and 39 hr per week are assigned more points than large agencies supervising operations for the same number of hours.

Question 6 gauges the financial stability of each organization by requesting applicants to indicate the percentage of their budget that is provided through contributions or donations. Scoring assignments are determined by the level of unsecured funding for all applicants regardless of fleet size.

The purpose of Question 10 is to measure the applicant's ability to ensure service reliability by determining the percentage of the agency's drivers who are unpaid volunteers. Applicants receive scoring assignments on the basis of their fleet size and the proportion of employees who are volunteer drivers. Applicants obtained fewer points for employing a larger percentage of volunteer drivers than paid drivers because of the absence of financial incentives to influence service delivery and employee turnover.

Question 11 is designed to evaluate applicants' ability to provide safe transportation service. Organizations indicate whether they require candidates for operator positions to submit a copy of their motor vehicle record before hiring. Applicants were also asked to indicate whether they require drivers to provide documentation that a physical examination was completed before the first day of employment. Although both of these personnel procedures are significant in providing safe service, scoring assignments for these questions were proportionately lower than for other questions because of the difficulty in validating responses.

SUMMARY OF OPERATIONS RESULTS

The responses to operational questions from 53 applicants are summarized in Table 2. The data are grouped by possible scoring alternatives for large and small agencies. As indicated previously, the objective of Question 3 (Table 1) was to penalize large organizations that assign supervisory responsibilities to a driver. However, 100 percent of the large agencies indicated that drivers are not responsible for supervising operations (Table 2). Although this variable did not influence applicants' scores, it will be used in future reviews to evaluate their assignment of supervisory responsibilities.

Table 2 indicates that only 38 percent of the large agencies allocate 40 or more hours to supervising operations. All the small agencies reported that their transportation programs are supervised less than 40 hr per week. Summary results for the breakdown of unsecured funding levels were consistent for both applicant groups. The largest difference in replies for unsecured funding levels corresponded to the 20 percent category. Eight percent of the large agencies disclosed that their total budget is provided through donations of 20 percent or more; 22 percent of the small agencies indicated that they relied on contributions for the same amount.

The percentage levels of volunteer drivers for both applicant groups were also comparable (Table 2). Twenty-two percent of the small agencies do not require the review of motor vehicle records for employment purposes, compared with 8 percent for the large agencies. Thirty-eight percent of the large agencies and 59 percent of the small agencies indicated that they did not require driver candidates to complete a physical examination as a condition of employment.

TABLE 2 OPERATIONS RESULTS

	Large Agencies		Small Agencies	
	N	Percent	N	Percent
Supervisor of operations				
Driver	0	0.0	0	0.0
Other	26	100.0	27	100.0
Total	26	100.0	27	100.0
Hours of supervision				
40 or more	10	38.0	0	0.0
20-29	6	24.0	9	33.0
20 or less	10	38.0	18	67.0
Total	26	100.0	27	100.0
Unsecured Funding				
20% or more	2	8.0	6	22.0
10-19%	4	15.0	3	11.0
5-9%	4	15.0	4	15.0
1-4%	12	46.0	11	41.0
0%	4	15.0	3	11.0
Total	26	100.0	27	100.0
Volunteer Drivers				
50 % or more	3	12.0	1	4.0
10-49%	2	8.0	0	0.0
1-9%	1	3.0	2	7.0
0%	20	77.0	24	89.0
Total	26	100.0	27	100.0
Use of Motor Vehicle Records for Employment Purposes				
Yes	24	92.0	21	78.0
No	2	8.0	6	22.0
Total	26	100.0	27	100.0
Use of Physical Examinations for Employment Purposes				
Yes	16	62.0	11	41.0
No	10	38.0	16	59.0
Total	26	100.0	27	100.0

QUESTIONNAIRE DESIGN FOR MAINTENANCE VARIABLES

Table 3 gives examples of questions used to evaluate applicants' management procedures to maintain equipment and extend the useful life of vehicles. Question 15 is designed to assess the preventive maintenance procedures completed by applicants without assistance from vendors. Scoring assignments were based on providers' ability to reduce vehicle downtime and mileage by completing maintenance procedures without outside assistance. Scoring assignments were aggregated for each type of preventive maintenance procedure completed by the applicant's staff. Large and small agencies were evaluated by identical scoring assignments.

The ability of organizations to monitor the condition of their equipment is measured by evaluating where vehicles are parked overnight (Table 3). Applicants obtained more points by indicating that vehicles are parked overnight in a central location. Applicants were also evaluated on their ability to protect vehicles from vandalism. Organizations obtained more points if they park vehicles in areas with security fencing.

SUMMARY OF MAINTENANCE RESULTS

The results of the responses to the maintenance questions are summarized in Table 4. The data are grouped together by possible scoring alternatives for large and small agencies. The results indicate that there is little difference between large and small agencies in the amount of preventive maintenance procedures completed without outside assistance. Eighty percent of the large agencies reported that they do not complete any repairs in-house, compared with 82 percent of the small agencies.

The tabulated responses to Question 16 indicate that agencies park their vehicles in a variety of locations. Fifty-four percent of the large agencies park their vehicles at drivers' homes in combination with other locations. Table 4 indicates that 81 percent of small agencies park vehicles overnight at a program site. Agencies also differed in the amount of security fencing provided for their vehicles. Fifty-eight percent of the large agencies indicated that security fencing is not provided, compared with 82 percent of the small agencies.

SUMMARY OF SERVICE NEEDS RESULTS

Table 5 summarizes a ranking of the average number of miles operated per month for each vehicle in an organization's fleet. Agencies were asked to provide the total number of miles operated per month for all vehicles. The data were sorted in descending order by using data base management functions. Scoring assignments were based on the mean and standard deviation of the sample and the question's weighted point value. The question weight for this variable was 12 points. Agencies that ranked above the mean value obtained more than 50 percent of the total possible points.

Scoring assignments were established by categorizing point values on the basis of the standard deviation of the sample. Data ratios were cross-referenced by checking current odometer readings in relationship to the model year of each vehicle in an agency's fleet. The table indicates that 8 of the 10 agencies with the highest average vehicle mileage operate fewer than six vehicles.

This type of measurement technique was also used to evaluate the influence of proposed projects on ridership and fleet age by ranking the number of clients transported per the combined number of requested vehicles and base fleet vehicles that have not exceeded useful life standards.

SUMMARY OF FINDINGS

Figures 1 and 2 summarize average criterion scores for large and small agencies. The total possible points for each criterion is indicated by the placement of a square symbol. The results

TABLE 3 EXAMPLES OF SCORING ASSIGNMENTS FOR MAINTENANCE QUESTIONS

15. What preventive maintenance items does your agency complete without the assistance of an outside contractor, service station, or garage?

		LARGE AGENCIES	SMALL AGENCIES
Oil and Lube Filter Change	____	(1)	(1)
Change Transmission Fluid	____	(1)	(1)
Flush Radiator/Change Coolant	____	(1)	(1)
Replace Spark Plugs	____	(1)	(1)
Contract all maintenance	____	(0)	(0)

16. Where are your agency's vehicles parked overnight?

		LARGE AGENCIES	SMALL AGENCIES
Drivers' Homes	____	(0)	(2)
Program Site(s)	____	(6)	(6)
Parking lot furnished by Government Agency	____	(6)	(6)
Other (Please Specify)	____________		

TABLE 4 MAINTENANCE RESULTS

	Large Agencies N	Large Agencies Percent	Small Agencies N	Small Agencies Percent
Preventive Maintenance Items Completed In-House				
0 Items	21	80.0	22	82.0
1 Item	2	8.0	2	7.0
2 Items	1	4.0	0	0.0
3 Items	0	0.0	0	0.0
4 Items	2	8.0	3	11.0
Total	26	100.0	27	100.0
Location of Parked Vehicles				
Drivers' Homes	3	11.0	5	19.0
Program Site/ Public Agency	9	35.0	22	81.0
Combination of Locations	14	54.0	0	0.0
Total	26	100.0	27	100.0
Security Fencing Provided				
All Vehicles	1	4.0	3	11.0
Some Vehicles	10	38.0	2	7.0
No Vehicles	15	58.0	22	82.0
Total	26	100.0	27	100.0

TABLE 5 SAMPLE RANKING OF NUMBER OF MILES OPERATED PER VEHICLE (QUESTION WEIGHT = 12, SAMPLE MEAN = 1,476, STANDARD DEVIATION = 918)

SIZE	RANK	AGENCY NAME	AVG. NUMBER OF MILES PER MONTH, PER VEHICLE	SCORE
Small	1	Vector Industries	4400.0	12
Small	2	Eastern Shore Rural Health	4000.0	12
Large	3	Lewis Puller Center	3100.0	10
Small	4	Danville Association ARC	3063.0	10
Small	5	Central Virginia Health Ctr.	3000.0	10
Small	6	Friendship Industries	2862.5	10
Small	7	Mental Retardation Services	2800.0	10
Small	8	Goochland Fellowship	2750.0	10
Small	9	Northwestern Workshop	2520.0	10
Large	10	New River Valley Workshop	2337.5	8
Large	11	Rappahannock Adult Activities	2222.2	8
Large	12	Sussex Adult Activity Service	1943.7	8
Large	13	ARC Greater Prince William	1832.8	8
Large	14	Community Alternatives	1783.3	8
Large	15	Rappahannock AAOA	1750.0	8
Large	16	Marc Workshop	1666.7	8
Large	17	Mountain Empire of the S.West	1575.4	8
Large	18	Peninsula Agency on Aging	1471.4	4
Small	19	Richmond Community Senior Ctr	1426.0	4

Double underline indicates - Greater than Mean Value

Total Number Ranked = 53

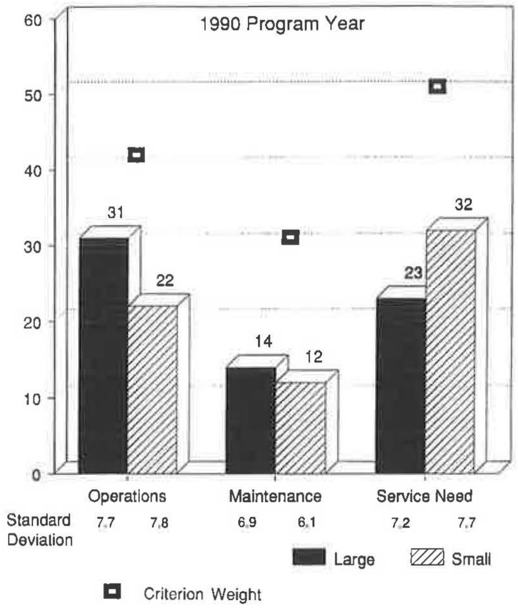

FIGURE 1 Average scores by criterion and fleet size—operations, maintenance, and service need.

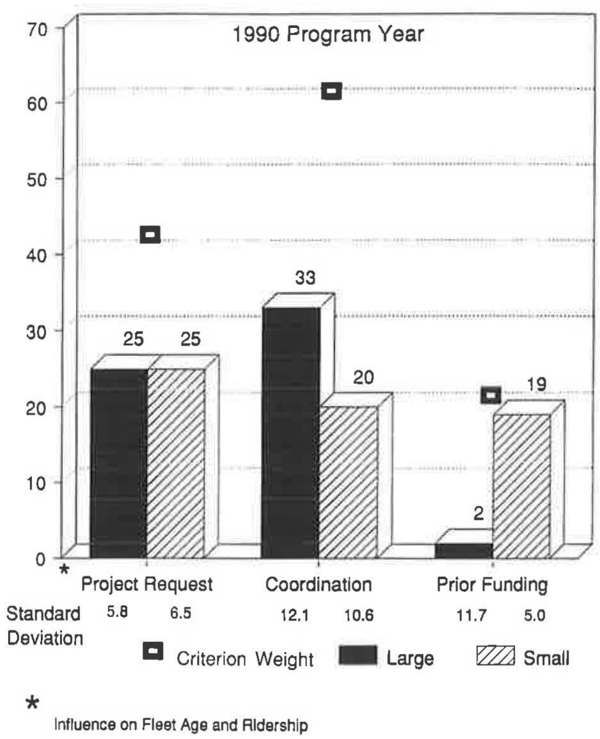

FIGURE 2 Average scores by criterion and fleet size—project request, coordination, and prior funding.

indicate that average criterion scores for operational procedures, maintenance procedures, service need, and the proposed project's influence on ridership and fleet age differed by fewer than 10 points for large and small agencies. Only the coordination criterion and the Section 16(b)(2) funding history criterion differed significantly. The standard deviation values were also similar except for the coordination and prior funding criteria.

Of the seven questions used to evaluate operations strategies, the average difference in scores for all variables was 1 point (Figure 1). This result can be attributed to the frequency of similar responses from large and small agencies to questions concerning defensive driver training and unsecured funding levels. Large agencies obtained, on the average, more points than small agencies for the use of physical examinations as a condition of employment. However, the question's low scoring assignment offset the influence of the average point spread between the two groups. This factor contributed significantly to reducing overall scoring differences between groups for this criterion.

The differences in maintenance criterion scores (Figure 1) were also insignificant for large and small agencies because of the type of measurement techniques applied to evaluate applicants and the similarity of responses received. The service need criterion results (Figure 1) indicate that the availability of public transportation is similar for large and small agencies. In addition, the use of applied measurement techniques to evaluate service need indicates that both groups accumulate similar vehicle mileage per month. Service need scores differed greatly in the average number of clients transported per month for all vehicles excluding spare vehicles. Large agencies ranked proportionately lower for this ratio than small agencies.

The variables used to measure the proposed project's influence on fleet age and ridership included service use alternatives and the number of clients transported per vehicle less than 5 years old or with less than 100,000 accumulated miles (Figure 2). Average criterion scores were similar for both groups because most applicants indicated that requested equipment would be used to replace vehicles. Also, the ranking of data for client ridership and fleet age generated an even distribution of scoring assignments for the two groups. Coordination scores, on the average, were much greater for large than small agencies. Large agencies obtained more points by demonstrating a more active involvement in maintaining cooperative service arrangements than small agencies. Average scores for the prior funding criterion reflect that large agencies have received Section 16(b)(2) funding more frequently than small agencies in the past 2 years.

In 1990, the described methodology caused more small fleet agencies to be recommended for funding than in previous years. Sixty-three percent of the small agencies that applied for financial assistance were funded for capital assistance, and 8 of the 10 applicants ranked highest were small agencies. Evenly distributed applicant scores for both groups and lopsided prior funding scores, which favored small agencies, caused the shift in funding.

CONCLUSION

It is uncertain that the continued use of this methodology will produce similar results, because applications are not received from the same organizations each year and agencies' operating practices are subject to change. However, it is certain that future applicants will be assessed by specific, consistent scoring procedures, thus increasing the ability of the administering agency (VDOT) to screen applications equitably and make effective planning decisions.

The methodology reduced scoring variance compared with previous reviews. However, the use of discretionary scoring assignments established a bias toward certain management procedures and practices. The evaluation process could be improved by designing more precise standards to gauge responses to fixed-alternative questions. In addition, future scoring assignments should not undervalue the significance of independent variables, such as safety procedures and personnel policies, that greatly influence program goals yet require support documentation to validate data.

Consideration should be given to reducing the criterion weight for prior funding opportunities. Although this criterion assists in providing a more even distribution of equipment, it does not guarantee improved funding for applicants that provide safe, reliable transportation service where public transportation service is unavailable.

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Implications of Transit Drug Testing and Maintenance Service Procurement for Small Urban and Rural Systems

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In recognition that drug use in the workplace is a pervasive problem, in 1986 an executive order was signed by the president calling for a drug-free workplace. As a result, the U.S. Department of Transportation, in September 1987, became the first executive agency to adopt a drug-testing policy. The origins and current status of transit industry drug-testing requirements for safety-sensitive workers are reviewed. Drug testing has been shown to effectively discourage the abuse of drugs. Currently, UMTA's drug-testing requirements have been suspended. Congress is expected, however, to provide UMTA the authority to reinstate drug-testing requirements. Small urban and rural transit agencies are concerned that the implementation and enforcement of drug-testing guidelines and regulations will place a severe and disproportionate administrative burden on them. Testing requirements are perceived by some as rendering it difficult or impossible to purchase maintenance and other support services. Most small agencies that buy maintenance services currently do so through small purchase agreements. They do not purchase services through the competitive bidding process. To examine the accuracy of the perception of the drug-testing issue in the transit industry, a limited number of agencies that competitively bid and procure maintenance services were surveyed. Data collected indicate that maintenance service contractors are generally willing to comply with drug-testing requirements. Furthermore, most reported good service and indicated that they had accrued cost savings through competitively awarded maintenance contracts.

The original U.S. Department of Transportation (DOT) drug-testing requirements for transit workers in safety-sensitive areas were issued in November 1988. They were to be implemented on December 21, 1989, at transit systems in urban areas with populations greater than 200,000 (*1*). Transit systems serving urban areas with populations less than 200,000 were to certify compliance by December 21, 1990, and states were to certify compliance by their rural transit subgrantees by December 21, 1990. [Rural transit operations (in areas with urban populations less than 50,000) receive funds through Section 18 of the Urban Mass Transportation Act of 1964, as amended. However, states are the recipients of these funds, and the transit agencies are subgrantees. Therefore, the state is the grantee of the federal government, and the state must certify compliance with drug testing.]

After several challenges to the legality of drug testing, the Amalgamated Transit Union won a judgment to suspend UMTA's authority to require drug testing. The U.S. Court of Appeals unanimously ruled that when Congress added Section 22 (Safety Authority) to the Urban Mass Transportation Act of 1964, it intended to give UMTA the authority to deal with safety hazards in "a manner that requires case-by-case development of local solutions." It was not intended to do so "via federally mandated, uniform rulemaking procedures that may not be responsive to concerns at the local level" (*Amalgamated Transit Union et al. versus Samuel K. Skinner, Secretary of Transportation,* United States Court of Appeals for the District of Columbia Circuit, argued December 14, 1989, and decided January 19, 1990, pp. 14–15).

The drug-testing rules are currently suspended, and DOT has authored legislation to grant UMTA authority to address and resolve safety problems through a federal mandate (*2*). Another version of the drug-testing bill expanded UMTA's authority to include additional testing for alcohol (*3*). Regardless of the exact language of the final bill, it is likely that drug testing will be reinstated.

There is evidence that many urban transit system managers and employees view drug testing as another necessary administrative burden for their safety-sensitive, labor-intensive industry. The American Public Transit Association Drug and Alcohol Task Force has conducted a survey of the drug-testing practices of approximately 450 urban transit systems (*4*). Of 240 agencies responding to the survey, 155 had initiated drug-testing programs before or shortly after the December 21, 1989, deadline for transit systems serving large urban areas. Of the 155, approximately 80 percent have continued to test even though UMTA's requirement has been suspended. These results suggest that most urban transit systems that have adopted drug-testing procedures recognize the growing consequences of drug abuse in the workplace. Twenty-six of the agencies surveyed had implemented drug-testing programs as early as 1985, 4 years before UMTA's requirements.

Rural agencies have been more reluctant than their large, urban counterparts to adopt drug-testing programs. It has been argued that drug testing creates a costly administrative burden that far outweighs the promised safety benefits (*5*). In addition, small systems are less self-sufficient and more often dependent on contractors' support services for maintenance, fueling, emergency services, and so forth. Small rural systems, for example, say that they would find it difficult, if not impossible, to impose and enforce drug testing on their contractors.

The issues concerning the difficulty of enforcing drug-testing requirements on contractors working for small transit

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systems are critical. Convincing arguments are set forth that the administrative costs of drug testing are a burden for very small transit systems (e.g., those systems with fewer than eight vehicles). However, the research findings described in this paper indicate that even small systems can find support service contractors that are willing to comply with drug testing if they procure services by awarding contracts competitively. It is also likely that transit systems will accrue cost savings as a result of competitively contracting for support services (if they are not already purchasing services through competitively bid, written contracts).

The researchers identified and interviewed 23 transit operators that procure support services (maintenance or maintenance plus some aspect of route operations) through competitive awards of contracts. Of those that had discussed drug testing with their contractors, the majority found that the contractor was willing to comply. In addition, most reported good service and have accrued cost saving through competitive contracting.

DRUG TESTING ORIGINS: HISTORICAL CONTEXT

Drug abuse is a serious problem for public-sector service providers and industry. It is estimated that drug abuse costs the economy $26 billion annually (*6*). More than $16 billion of the cost is in industry and work-related activities and is due to such factors as lost productivity, absenteeism, disability claims, and theft (*6*). The National Council on Alcoholism sets the cost to industry of alcohol abuse at approximately $20 billion annually (*6*). Employees with alcohol problems may cost their employers as much as $2,500/year in production losses and absenteeism (*6*).

The Federal Railroad Administration recorded evidence of alcohol and drug-related accidents occurring between 1975 and 1983. Their data indicated that these accidents resulted in 34 fatalities, 66 nonfatal injuries, and $28 million in lost railroad property and direct costs (*7*). Craft Consultants, a drug education and counseling firm, estimates that 4 million workers abusing drugs in the workplace have been referred for treatment within the past few years (*6*).

Despite the extensive level of research conducted in the area of work-related drug and alcohol abuse problems, the exact costs to industry and public agencies are not easily quantifiable. It is often difficult, for example, to identify the effects of drug and alcohol abuse on productivity, absenteeism, and employee turnover rates. These kinds of costs are intangible and difficult to examine objectively.

Because the effects of drug abuse are clearly significant, small and large transit agencies alike are faced with developing quality employee assistance programs to screen and identify high-risk employees. A negative message that may be perceived is that such programs stress punishment instead of recovery. The issues surrounding drug testing, therefore, must be realistically addressed, balancing employee rights against public confidence in the safety of public transportation.

Given the seriousness of the productivity losses and the potential decline in public safety, agency actions to curb drug and alcohol abuse by employees in the workplace are needed. Employers who are combating drug abuse problems are most likely to maintain a high success rate if they initiate educational programs for their employees. This tends to enhance confidence among employees, management, and the public, because it emphasizes treatment rather than punishment.

Drug Testing Precedents

In 1981 the military began a program of random drug testing. As a result, from 1982 to 1988 there was an 82 percent reduction in drug use (*8*). The Coast Guard has also had success with random testing. On implementation of a drug-testing policy, positive tests for drugs were reduced from 10.3 percent in 1983 to 2.8 percent in 1988 (*9*). Evidence of the effectiveness of drug testing in the military and the Coast Guard is clear. These results, coupled with the gravity of the drug problem, ultimately led to increased societal support for drug testing.

In 1986, President Reagan signed Executive Order 12564, which calls for a drug-free workplace emphasizing public health, safety, and national security. DOT, in September 1987, became the first executive agency to adopt a drug-testing policy. Rules for drug testing by all administrations of DOT were first published in the November 21, 1988, issue of the *Federal Register* (*10*). Whereas test cases in the court system have indicated that most DOT administrations have the authority to mandate drug testing, UMTA does not. Its drug-testing rules are currently suspended. It is, however, likely that Congress will eventually provide UMTA with the authority to mandate drug testing and that future drug-testing rules will look much like the original rules.

Who Is Subject to Screening for Drugs?

UMTA's suspended drug-testing program is limited to employees in agencies whose responsibilities affect the safety and security of the public. Employees in safety-sensitive positions include those providing support in vehicle operation activities such as revenue vehicle movement control, including dispatchers and others working in safety and safety-training positions, and revenue vehicle inspection and maintenance personnel, including mechanics and technicians who perform inspection and maintenance work on revenue vehicles or their components.

Contract service employees are subject to testing if their work is ongoing, continuous, and routine. There must be a "relationship" between the agency and the service contractor, and the agency must certify that the contractor is conforming to the drug-testing requirements. A relationship is construed to include such things as a small purchase agreement to purchase fuel from a local service station. It does not include emergency services such as a call to a local service station to repair a flat tire during a road call. Any maintenance service contract that involves functions such as servicing, fueling, inspection, and preventive maintenance of revenue vehicles, however, is covered by the UMTA rule.

Nonvehicle maintenance support, including passenger shelters and equipment, and communication systems are also covered under the UMTA rule. Supervisory personnel subject to the UMTA rule include those who supervise employees performing any of the services mentioned above.

Goals of Drug Testing in the Public Transportation Industry

The primary goal of drug testing in public transportation is to identify, using objective criteria, employees who pose a threat to public safety. By using this controversial policy to curb the abuse of drugs in the workplace, confidence in public transportation is more likely to be sustained.

Procedural Guidelines for Drug Testing

In March 1989, UMTA began requiring any transit agency receiving federal financial assistance through Sections 3, 9, or 18 of the Urban Mass Transportation Act of 1964, as amended, to establish antidrug programs consisting of

- A policy statement on drug use in the workplace;
- An employee and supervisor education and training program;
- A drug-testing program for employees and applicants for employment in safety-sensitive positions; and
- Administrative actions for record keeping, reporting, release of information, certification of compliance, and requests for waivers.

It granted $740,000 to provide several states with funds to develop comprehensive demonstration models of drug-free programs (*11*). These procedural documents and courses provide much direction for UMTA's drug-testing rules and procedures. It is easy to understand why a small transit agency manager would feel overwhelmed by all the administrative details in the guidelines. The detail is necessary to ensure prudent, equitable, and unbiased application of drug testing. For brevity, only three pivotal procedural aspects are described below.

Drugs Evaluated by Tests

The drugs covered under UMTA regulations include cocaine, heroin, amphetamines, marijuana, and Phencyclidine (PCP). Urinalysis is used to determine the presence of drugs. Testing for additional drugs is permissible but may be problematic. If employers choose to test for other drugs, including alcohol, they can do so if they follow correct procedures designated for the particular drug or alcohol. If they do so, however, a separate sample must be taken. The DOT sample cannot be used for this purpose, and the Department of Health and Human Services does not certify laboratories for analyzing drugs beyond the five prescribed by UMTA. A recent article (*12*) pointed out that

> in the drug testing area, DOT felt it necessary to limit testing to labs certified by the Department of Health and Human Services. It questions whether alcohol testing is sufficiently simple to obviate the need for special certification. There are also issues concerning preserving the chain of custody of samples and whether medical review officers should be required.

As an example of the seriousness and widespread abuse of alcohol, during a 7-year period DOT's inspector general found that 10,300 individuals who had previously had their driving licenses revoked for driving while intoxicated became certified pilots (*9*). DOT found that in 1986, 30 percent of 300 randomly selected truck drivers tested positive for drugs or alcohol (*9*).

When Are Employees Tested?

Testing of employees who perform sensitive safety functions is to be carried out under the following circumstances (*13*,p.21):

- Before employment for, or assignment to, a safety-sensitive position;
- If they contributed to, or cannot be completely discounted as a contributing factor in, an accident;
- On an unannounced and random basis (the number of tests conducted annually must equal 50 percent of all employees who perform sensitive-safety functions);
- Before returning to duty after having refused a drug test or after not passing a drug test; or
- For a reasonable cause.

Sanctions for Employees Testing Positive for Drugs

UMTA requires that employees who test positive for drugs be immediately removed from safety-sensitive positions. Employees must comply with a "return to work" drug test before reinstatement to a safety-sensitive position. In a March 1990 seminar sponsored by Batelle Laboratories on drug testing in the transit industry, workshop leaders suggested that an employee who is suspected of drug abuse but refuses to be tested should be penalized more severely than an employee who agrees to be tested and tests positive. Refusal to comply might well be construed as insubordination to be punished by immediate suspension or termination. Before returning to work in a safety-sensitive position, an employee must undergo a drug test (*13*,p.20).

LEGAL CHALLENGES TO DRUG-TESTING PROGRAMS

The legal issues surrounding drug testing involve questions of employee privacy rights under the Fourth and Fourteenth amendments to the Constitution, public safety, employer interest in ensuring the highest employee performance standards, and employer protection from legal liability in accident cases. The Fourth Amendment protects against unreasonable search and seizure of one's person or property. The Fourteenth Amendment addresses issues concerning equal treatment and employees' privacy rights. Two approaches used when addressing privacy rights are the traditional or warrantless administrative search and the "balancing" standard. The balancing standard emphasizes an interpretation that is relative to a case-by-case circumstance or situation (*14*).

Warrantless Searches

Drug testing of employees does not require warrants because tests are not used for criminal prosecution. Warrantless administrative searches are justified by strong state interest in highly regulated industries. Because the information received from drug testing is directly related to the safety of the public, the argument is that the privacy expectation of the individual is lowered.

Some limitations on constitutional issues between private and public agencies are unclear. One recent court case ruled that a drug-testing program in the workplace involved state action because the private employer was a subcontractor of a state agency (*Craft versus Pace of South Holland,* 1988) (*15*). Nonconstitutional limitations include state drug testing laws, state constitutions, torts, employment laws, and certain federal statutes.

Employee Privacy Versus Public Safety

A military court's ruling in *Committee for G.I. Rights versus Callaway* (*16*) in 1975 set a precedent for subsequent court decisions. In this case, testing for administrative purposes allowed the military to test without reasonable cause. When individuals are singled out, reasonable cause is required.

Strong state interest, lowered expectations of privacy by employees, a low level of intrusiveness, and procedural protection for employees are factors that influence the courts to rule in favor of drug testing. In *Division 241, Amalgamated Transit Union (AFL-CIO) versus Suscy* (*17*), for example, bus drivers were required to submit to urine tests (not random) on the basis of a lowered expectation of privacy, a strong state interest, and procedural protection for those being tested. In *Shoemaker versus Handel* (1986) (*17*), the first random drug-testing case, the U.S. District Court in New Jersey ruled that the state's interest in a horse-racing track reduced the expectation of privacy by jockeys. The court ruled that the state's interest in a highly regulated industry took precedence over the privacy rights of the individual jockey.

In contrast, in *Amalgamated Transit Union, Local 1277, AFL-CIO versus Sunline Transit Agency* (*17*) the court concluded in 1987 that "the public's interest in safety" was important, but in this case random testing did not conform to reasonable cause requirements. The Ninth Circuit Court of Appeals in San Francisco in *American Federation of Government Employees versus Carlucci* (*17*) concluded that a random urinalysis was inconclusive evidence of impairment or abuse. The U.S. Circuit Court of Appeals overturned the lower court's ruling and unanimously upheld random drug testing (*18*). The court ruled that the issue of employee privacy is "outweighed by the Department's (DOT) compelling interests in preventing drug use among employees who are involved in public safety or national security." The Supreme Court later refused to hear an appeal of the case (*19*).

Related Legal Problems

Claims of employment discrimination from wrongful discharge, aside from those arising under the United States Constitution, include (*a*) state constitutional protection, (*b*) intrusiveness of urinalysis procedures, and (*c*) the confusing situations created by suits brought by plaintiffs under the Federal Rehabilitative Act of 1973 and Title VII of the Civil Rights Act of 1964.

A job applicant who is refused employment or who is disciplined on the basis of tests that reveal the presence of drugs could claim unfair discrimination under the Federal Rehabilitative Act. The act does not protect drug abusers who cannot perform their jobs as a result of drug abuse or when such impairment causes a threat to company property and personnel. A person who refuses rehabilitation is not eligible to collect either unemployment benefits or workman's compensation. The act applies to both public and private agencies that accept federal funding.

The Civil Rights Act of 1964 prohibits discrimination based on race, sex, religion, or national origin. If an employee uses the act in a defense, the employer must counter allegations by stating that employee discipline was predicated on poor job performance. In *New York City Transit versus Beazer,* the Supreme Court upheld a policy that prohibited hiring narcotics users. This ruling disproportionately affected the black and Hispanic communities.

Many legal problems may be expected to emerge as a result of drug-testing regulations. The suspended drug-testing regulations require that transit agencies receiving federal funds certify that personnel performing safety-sensitive functions, including personnel who are not employees of the transit agency but are employees of support service providers, meet the drug-testing requirements. For example, if an independent garage performs routine maintenance on transit vehicles, employees performing routine maintenance must meet the same drug-testing requirements as the transit agency's own employees performing safety-sensitive functions. In addition, even though a transit agency does not purchase routine maintenance services through a competitively bid, written contract, and they are bought through a small purchase agreement with a local garage (such as using an oil company credit card to purchase services), the drug-testing requirements apply, and the transit agency has an informal contract with the garage performing the service.

Maze et al. have recently conducted a survey on the effects of drug testing on contracting for maintenance services in public transportation (T. H. Maze, K. M. Waggoner, M. E. Maggio, and J. Dobie, *A Manual on Contracting for Maintenance Services,* research in progress). The results indicate that drug testing may well present administrative burdens, particularly for small transit operators. Moreover, careful management and monitoring of maintenance contractors is likely to become the norm should UMTA be granted authority to initiate an aggressive drug-testing program, including random testing, in public transportation agencies receiving federal funds. In the following section of this paper, the results of the survey are presented.

FINDINGS OF SURVEY

The primary objective of surveying agencies that contract for maintenance was to collect data on the state of the practice of maintenance contracting in the transit industry (T. H. Maze, K. M. Waggoner, M. E. Maggio, and J. Dobie, *A Manual on Contracting for Maintenance Services,* research in progress). Surveying expected drug-testing practices was a secondary reason. The results concerning expected drug-testing practices, however, are the focus of this discussion. The survey was conducted by telephone with some in-person follow-up. Respondents were predominantly small urban transit systems and rural agencies.

Survey Methodology

Although a preponderance of evidence suggests that competitively contracted maintenance services frequently reduce operating costs, few transit agencies contract for these services (*20*). The rationale for retaining in-house maintenance capabilities included factors such as better control over quality of maintenance, better control over the equipment, ability to specialize in transit equipment maintenance, integration with other service functions, and retention of equipment maintenance expertise in-house.

What appears most troublesome is that small agencies tend to have their vehicle maintenance conducted through private service providers using small purchase agreements rather than through competitively awarded contracts. Common arguments provided by small agencies (usually rural systems) against competitively bidding maintenance services are that (*a*) the bidding mechanism is too complex and thus an administrative burden, (*b*) the agency is currently able to "shop around" to find the best price, (*c*) service providers are unsophisticated and thus unable to bid on services, (*d*) contracting would lock them into a service provider that would be unresponsive to their needs, and (*e*) contracting would result in their losing absolute control over equipment.

On the other hand, several small agencies in rural areas do competitively contract for maintenance services. For the most part, they report receiving excellent service at lower costs.

To identify agencies with positive or negative contracting experiences, staff members with transit oversight responsibilities at state departments of transportation were contacted to identify agencies that currently contract for maintenance services. Agencies from 45 states were contacted (the states that were not contacted were Alaska, Hawaii, Delaware, Rhode Island, and New Mexico). Twenty-five state contacts did not think that any systems contracted for maintenance in their state. Four contacts did not believe that there were any agencies that competitively contracted for maintenance in their states but were not certain. Fourteen contacts were able to identify agencies that competitively bid contracts for maintenance services. Through DOT contacts, 23 agencies that competitively contract for maintenance services were identified.

This process has missed some agencies. The purpose of the survey, however, was not to identify the entire population of small transit systems that contract for maintenance services; it was to identify the state of the practice. A sample of systems was identified to begin determining trends in the industry.

Survey Results

Table 1 gives a summary of the findings. The systems surveyed represent a cross section of the country. Fourteen agencies had discussed drug testing with their contractors, and the contractors agreed to cooperate. Two agencies commented that their contractors had already begun planning for drug testing: the contractor for one of the agencies had its employees adopt a drug policy statement, and the other claimed that the contractor had already developed a plan for the administration of drug testing. Two agencies contracted with firms that had their own drug-testing policy in place and are currently conducting drug testing.

Two agencies had not discussed drug testing with their maintenance contractors because they did not want to alarm

TABLE 1 ANTICIPATED CONTRACTOR COMPLIANCE WITH DRUG-TESTING REQUIREMENTS

Agency State	Agency Type	No of Vehicles*	Anticipate Drug Testing Experience**	Experience	Cost of Services***
Alabama	Section 18	12	No Problem	Good Service	Experienced Savings
Florida	Section 9	34	Program In Place	Good Service	Experienced Savings
Iowa	Section 18	35	No Problem	Good Service	Experienced Savings
Kansas	Section 18	26	Some Problems	Good Service	Experienced Savings
Kentucky	Section 18	12	Have Not Discussed Yet	Just Started	No Basis For Comparison
Maine	Section 18	18	Contractor Uninterested in Testing	Good Service	No Basis For Comparison
Maine	Section 18	23	Have Not Discussed Yet	Mixed Experience	No Basis For Comparison
Michigan	Section 9	20	No Problem	Good Service	Experienced Savings
Michigan	Section 18	6	No Problem	No Response	No Response
Minnesota	Section 18	47	Phase-out Contract For Other Reasons	Starting Inhouse	Anticipated Savings Inhouse
Ohio	Section 9	16	Testing Policy In Place	Good Service	Experienced Savings
Ohio	Section 9	10	No Problem	Good Service	No Basis For Comparison
Ohio	Section 9	27	No Problem	Good Service	Experienced Savings
Oklahoma	Section 18	26	Some Contractors May Not Cooperate	Good Service	Experienced Savings
Oregon	Section 18	2	No Problem	Acceptable Service	No Savings or Increase
Oregon	Section 18	2	No Problem	Good Service	Experienced Savings
Oregon	Section 18	12	Program In Place	Good Service	Experienced Savings
Oregon	Section 18	10	No Problem	Good Service	Experienced Savings
Pennsylvania	Section 18	5	Contractor Is Unlikely To Cooperate	Service Unsatisfactory	No Basis For Comparison
Vermont	Section 18	20	Developed Plan For Testing	Good Service	Experienced Savings
Washington	Section 18	30	No Problem	Good Service	Experienced Savings
Washington	Section 18	17	No Problem	Good Service	No Basis For Comparison
West Virginia	Section 18	15	No Problem	Good Service	Experienced Savings

* The number of vehicles operated by Section 18 agencies were derived from: Community Transportation Association of America, "A Directory of UMTA-Funded Rural and Specialized Transit Systems," Prepared for the Urban Mass Transportation Administration, Washington, D.C., 1990, DOT-T-90-05.

** Since none of the agencies had in fact established a complete drug testing program, managers were forced to speculate on the problems they would encounter when they asked their service contractor to comply with a drug testing program.

*** None of the agency managers had conducted an economic analysis to estimate whether there were savings that resulted from contracting for services. Managers that estimated a savings (or a cost increase) did so based on judgement.

the contractors at a time when the status of drug testing was unclear. Two agencies had multiple contracts, in which different contractors were used at different locations. They said that it was likely that some contractors would cooperate, whereas others would not (primarily because of the low volume of transit business).

Two agencies perceived that their contractors would not be willing to comply with drug-testing requirements. One representative said that if a new contractor could be found, it would cooperate through rebidding. Another agency was unsure whether it could find any maintenance service providers who would submit their employees to drug testing. One agency was phasing out its current contract because it was developing in-house maintenance capabilities.

Of those agencies that had planned to implement drug-testing requirements for contractors, some planned to have the contractor pay for the cost of testing as a cost of doing business. Other agencies planned to reimburse the contractor for the cost of the test and the employee's time while traveling to and from the sample collection site.

The managers of the agencies were also asked if they had experienced good service from their contractors. Most agreed that they had a good relationship with their contractors and that they were receiving good service. In follow-up case studies, it was found that strong contract administration by the transit agency, regular communications, and flexibility were attributes of successful contracting (T. H. Maze, K. M. Waggoner, M. E. Maggio, and J. Dobie, *A Manual on Contracting for Maintenance Services,* research in progress).

Some systems surveyed have always contracted. As a result, they did not have a point of reference for maintenance costs without contracting. Most who had a point of reference believed that competitively bid contracts have resulted in cost savings.

The results of the survey are clear. Competitively bid, contracted maintenance services generally result in transit system savings, and agencies are generally satisfied with the quality of service. Some agency managers believe that the drug-testing requirement would result in the need to rebid services. In one case it was stated that no local contractors would want the work under the drug-testing requirements. Nonetheless, a majority of those contacted agreed that their contractors would comply with drug-testing rules.

Although compliance with drug-testing requirements does not appear to be an impossible barrier for most small transit agencies, it could present a significant burden for very small agencies (e.g., those with fewer than eight vehicles). Because of a very small agency's lack of maintenance work volume, a contractor may not find the work attractive enough to compensate for the added administrative burden.

As other transportation industries (e.g., trucking) come into compliance and industry in general adopts the requirements, testing is likely to become more commonplace and accepted by mainstream employees. For example, when the DOT requirements are fully applied across all transportation modes (except transit) by the end of 1990, roughly 4 million transportation workers in all locations in the United States will be covered by drug-testing programs (*21*). Therefore, in time, drug testing is likely to lose its stigma, and contractors attracted by the work will lower their resistance to drug-testing requirements.

CONCLUSIONS

Drug testing has been shown to significantly deter drug use by employees. Challenges to the constitutionality of drug testing, including random testing, have been defeated in the courts. The concern is that an alarming rate of drug abuse in the transportation sector may come to light as testing is implemented on a nationwide basis (*22*). Though there may well be some disruptions in work forces in certain modes of transportation should the rate of workers testing positive be high, the time has arrived for the transportation industry to move forward on this critical issue.

Testing is unquestionably an administrative burden for small agencies. This is a troublesome issue. State or association consortiums can assist small agencies in dealing with the burden. For example, transit agencies near each other could form consortiums and use the consortium's size to reduce the individual burden of contracting for maintenance services. Statewide transit associations could work with automotive service associations to identify potential contractors and develop and disseminate model contracting language and procedures.

The imposition of drug-testing requirements is likely to cause agencies not currently procuring service through competitive contracting to establish closer relationships with their maintenance providers. The strengthening of relationships is likely to result in more competitively awarded, written contracts. Though at first examination this appears to be an overwhelming burden to the "shade tree" mechanic, experience has shown that it is not an insurmountable impediment to a local business. Some small rural transit agencies competitively contract for maintenance using written agreements as short as one page, and local garages perform the work.

Procedures intended to minimize the administrative burden are becoming available for small agencies and their third-party contractors. The procedures are designed to provide for the development of consortiums of collection sites to minimize costs and enforcement problems and alleviate some of the record keeping and chain of custody problems that might otherwise be impossible to manage. This is expected to assist transit agencies, contractors, and the employees who will be subject to drug testing.

A positive factor associated with the drug-testing issue is reflected in Table 1. With the implementation of drug-testing requirements, more competitive contracting for vehicle maintenance is likely. Agencies that competitively award vehicle maintenance contracts are likely to accrue savings. There will necessarily be resistance to any new policy that adds to the administrative work load for agency directors. Whereas the sample size for this study was not large, agency directors interviewed for this study indicated that contracting for maintenance of their vehicles, and subsequent compliance with the federal rules on drug testing, were not insurmountable problems.

These findings are not meant to be a blanket endorsement for contracting for maintenance services under all circumstances. Very small agencies in remote areas may have a limited pool of private-sector maintenance service providers willing to compete for the transit agency's business. Although it is expected that such instances will be extreme (the automotive service industry has a low cost for entry and is highly competitive), the application of drug testing in such cases is likely to require that systems search for creative local solutions.

Finally, agencies considering contracting for maintenance services must be cautioned. Successful contracting requires continual monitoring and careful management of contracts. For maintenance contracting, this implies developing or having the contractor develop a rigorous preventive maintenance routine. Agency staff should regularly monitor invoices and inspect work to ensure that it is being completed to the agency's satisfaction. However, these same recommendations represent prudent practice for professional transit managers, and they should be followed by agencies that do not have written contracts and purchase maintenance services through small purchase agreements.

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Challenges for Integration of Alternative Fuels in the Transit Industry

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The implementation of alternative-fuel, heavy-duty engines is promoted under the Clean Air Act of 1990. The move toward alternative fuels finds impetus from the emission-reducing properties of alternative fuels and the need to reduce dependence on foreign petroleum supplies. The widespread use of alternative fuels faces three major integration challenges: (*a*) the leading alternative fuels have handling requirements that are different from petroleum fuels, and some are hazardous; (*b*) some have low energy densities and, at current prices, are more expensive per diesel fuel-equivalent unit of energy; and (*c*) the United States lacks an adequate ready supply of alternative fuels, as well as a high-volume, nationwide distribution network.

An overview of the physical and handling properties, the health hazards, and some of the supply issues related to the most widely used alternative fuels is provided. Four leading alternative fuels are discussed using experience derived from experimentation in the transit bus industry. Results generated in the transit bus industry have been used to analyze the use of alternative fuels in a "real-time" production environment. The transit bus industry provides the best source of empirical data on fleetwide implementation of alternative transportation fuels technology. Issues that confronted the transit operators and the experiences of some 40 different trials involving more than 200 coaches (in service in early 1991) in the United States and Canada were obtained (*1*).

Differences between properties of alternative and conventional (e.g., gasoline and diesel) fuels, and precautions that should be taken to guard against risks of handling alternative fuels and maintaining alternative-fuel engines, are identified. It is not suggested that alternative fuels present greater risks than conventional fuels, simply different risks.

The paper also counters some misconceptions concerning the hazards of integrating alternative fuels into transit fleets. Clearly, alternative fuels, and for that matter conventional fuels, present significant health and safety challenges. Experience through alternative-fuel vehicle demonstrations indicates that with proper training, facility design, and adequate precautions, alternative fuels can be handled safely by operations, service, and maintenance personnel.

Current Environmental Protection Agency (EPA) tail pipe emissions rules and the Clean Air Act of 1990 (as amended) are pressing transit managers to embrace alternative-fuel engine technology. In many cases, legislation has encouraged the introduction of alternative-fuel buses into transit fleets. The information presented should help transit managers select specific technology and prepare the work force and should help maintenance facilities safely operate alternative-fuel vehicles. The paper is not a complete overview of each technology. A thorough investigation into the costs and benefits is encouraged before implementation of alternative-fuel vehicles.

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CLEAN AIR ACT REQUIREMENTS

The Clean Air Act of 1970, which set forth clean air goals and emission standards for the nation, has been amended several times. Nonetheless, the United States has been unable to reduce ambient air pollution levels as the act requires. Extensions of deadlines for meeting air quality standards were granted repeatedly but expired in 1988. Finally, P.L. 101-549, which amends the 1977 Clean Air Act (P.L. 95-95), was signed into law on November 15, 1990. The most recent law is commonly called the Clean Air Act of 1990.

The new Clean Air Act sets standards for stationary and mobile sources of pollution and establishes incentives for emissions reduction. The sections of the act are as follows: Title I, Ambient Air Quality (smog); Title II, Motor Vehicles; Title III, Air Toxics (hazardous air pollutants); Title IV, Acid Rain (utility power plants); Title V, Permits (stationary or area source); Title VI, Stratospheric Ozone; Title VII, Federal and State Enforcement; Titles VIII-X, Miscellaneous; and Title XI, Job Loss Benefits. A detailed synopsis appears in the *Congressional Quarterly* (*2*) (the act itself is more than 300 pages).

Title II requires EPA to set forth, by January 1, 1992, emissions standards for urban buses for model year 1994 and thereafter. The standards may be based on and reflect industry costs, safety issues, and lead time factors, but they must require compliance with heavy-duty truck emissions standards for the same model year. In 1994, bus emissions of particulate matter (PM) may not exceed 50 percent of the 1994 truck standards. The EPA administrator may require that all buses placed into service in urban areas with populations exceeding 750,000 (1980) that have not met PM standards use alternative fuels. Title II specifies methanol, ethanol, propane, natural gas, or any comparably low-polluting fuel.

Compared with earlier EPA rules, the new act allows a slightly higher level of PM emissions for model year 1991 and 1992: 0.25 grams per brake-horsepower-hour (g/bhp-hr), decreasing to 0.10 g/bhp-hr in 1993 and beyond. The 0.10 level represents an 83 percent reduction in particulate emissions from 1988–1990 standards.

EPA has been charged with implementation and enforcement of the act and will be formulating and proposing amendments and administrative rules through 1991 and beyond. New heavy-duty truck standards, generally for vehicles with gross vehicle weight between 8,500 and 26,000 lb, on which bus standards will be based, are shown in Table 1.

Continuing in effect are EPA rules for transit buses and heavy trucks requiring a reduction in nitrogen oxides (NO_x) from 10.7 g/bhp-hr in 1989 to 5.0 g/bhp-hr in 1991. Trucks have until 1994 to meet the particulate standards, and in 1994 bus and truck standards may converge (*3*).

Standards for hydrocarbon emissions (1.3 g/bhp-hr) and carbon monoxide (15.5 g/bhp-hr) were made effective in 1987 and remain in force. By and large, these standards have been met.

Under authority found in enabling legislation, EPA also regulates vehicle exhaust and evaporative emissions as well as emissions from refueling of tanks and vehicles. National Ambient Air Quality Standards (NAAQS) have been established under EPA's regulatory authority. To reduce ozone concentrations in metropolitan areas, NO_x emissions standards were included in the NAAQS (40 CFR 80 and 40 CFR 86).

The heavy-duty truck fleet will be required to meet a phased-in reduction of hydrocarbon, carbon oxide, and NO_x emissions through 1998, with intermediate standards in 1994.

The new legislation directs the EPA administrator to set standards for carbon oxide emissions at cold temperatures, evaporative emissions, on-board vapor recovery systems, and reformulated and oxygenated fuel use and credits in nonattainment areas. The act sets fuel volatility standards, allowing an exception for gasohol. It also sets a maximum sulfur content for diesel fuel. (Gasohol is 10 percent ethanol and 90 percent unleaded gasoline. Diesel fuel sulfur content by 1993 must have a Cetane index below 40.)

LEADING ALTERNATIVE AND CLEAN-BURNING FUEL CANDIDATES

Current diesel engine technology cannot meet the EPA tail pipe emissions standard. The early deadline for buses has placed pressure on transit industry and equipment manufacturers to seek clean-burning alternative fuels.

It is clear that no single alternative fuel will emerge soon as the favorite, especially in the transit bus industry. Experimentation and engine testing necessarily have led to many candidates. The leading fuels that will meet the 1991 bus emissions standards or the 1994 truck emissions standards include methanol, compressed natural gas (CNG), ethanol, and liquefied petroleum gas (LPG). Reformulated gasoline and "clean diesel" fuel should also be included as possible clean-burning fuels. Although the main ingredient of reformulated fuel is a conventional fuel, reformulated fuels are clearly different from conventional fuels and have many desirable attributes. The feasibility of other alternative fuels, such as solar power, electricity, or hydrogen fuel, has not been demonstrated in the field, and so these fuels were excluded from this analysis.

UMTA has compiled a list of past, present, and likely future applications for capital assistance by transit agencies under its Alternative Fuels Initiative program. Applications since 1988 and "likely" future applications bring the total alternative vehicles under this program to 808 (*4*). Sixty-two percent of the past and expected applications are for CNG-powered buses, 13 percent are for LPG-powered buses, 13 percent are for ethanol-powered buses, and 5 percent for methanol-powered buses. The remaining applications included other technologies, particulate traps, and liquefied natural gas, or were undecided.

Methanol

Methanol, an alcohol fuel, is also known as methyl alcohol, wood alcohol, or carbinol. An oxygenated hydrocarbon, its molecular formula is CH_3OH. It is a clear, colorless liquid with a characteristic odor. It is derived from natural gas processing, gasification of coal, or wood-based refuse and other biomass sources. The conversion of coal and biomass to methanol is roughly twice as expensive as conversion from natural gas. Therefore, commercially available methanol is almost entirely derived from natural gas. The methanol-fueled heavy-duty engine is the only technology that has demonstrated its ability to meet the 1991 transit emission standards for both particulates and NO_x (*3*).

CNG

CNG is a clean-burning gaseous fuel that can significantly reduce hydrocarbon, NO_x, and carbon monoxide emissions from diesel levels. The gas is highly compressed when used as a fuel, to between 2,400 and 3,000 psi, to increase the available energy. This accounts for the necessity of strong, heavy (thickness of 0.25 to 0.5 in.) on-board steel or aluminum tanks.

CNG engines can meet the 1991 particulate emission standards. In fact, according to American Gas Association tests, CNG engines emit no PM. It is, however, proving difficult for CNG engines to meet the NO_x emission standards. CNG engines eliminate evaporative reactive hydrocarbons, and in three of four studies, current CNG technology exceeds EPA standards for exhaust reactive hydrocarbons. There appears

TABLE 1 HEAVY TRUCK EMISSION STANDARDS (BUSES MAY NOT EXCEED 50 PERCENT OF THESE LEVELS)

Hydrocarbons	0.39 g/mi	(1994-95:	0.49 g/mi)
Carbon Oxides	5 g/mi	(1994-95:	6.2 g/mi)
Nitrogen Oxides	1.1 g/mi	(1994-95:	1.38 g/mi)
Nitrogen Oxides	4 g/bhp-hr.	(1998)	

Note: 50% of trucks must comply by model year 1996, rising to 100% thereafter.

to be general agreement that hydrocarbons from exhaust will be well below EPA levels with advanced technology CNG engines now in development. Carbon monoxide emissions from CNG engines are more than 50 percent below those of gasoline engines (*5*).

Ethanol

Ethanol, an alcohol fuel, is also known as ethyl alcohol, grain alcohol, or just alcohol. An oxygenated hydrocarbon, its molecular formula is C_2H_5OH. It is water clear and has a neutral odor. Appearance and odor could be modified by adding nonhazardous components. Ethanol is produced through the fermentation of simple sugars or through other chemical and catalytic reactions. Most fuel ethanol in current use is fermentation ethanol, produced as a by-product of corn or wheat milling processes (*6*).

Ethanol engines produce only half the carbon monoxide of gasoline, significantly reduce PM, and emit no harmful hydrocarbons. There is contradictory evidence in emissions studies. One recent EPA study found an increase in hydrocarbon and NO_x emissions as a result of increased ethanol use (*7*).

Most ethanol used in fuel is in gasohol, which is sold in 42 states and accounts for about 9 percent of the total gasoline market (*8*). Though performance reports on gasohol use in automobiles are mixed, it is clear that with proper engine design and adjustment, ethanol blends, as well as neat ethanol, are appropriate, clean-burning fuels. Ethanol prices and supplies depend on the grain market and to a certain extent on the location of the wholesale and retail outlet. Nearly 1 billion gal of ethanol is used with gasoline in gasohol blends each year (*9*).

LPG

LPG is a gaseous fuel that may include propane gas, butane gas, or a mixture of the two. LPGs can be extracted from oil fields or derived as by-products of the petroleum refining process, specifically in refining and cleaning up natural gas. LPG is gaseous under normal atmospheric conditions, but it may become a liquid when compressed or refrigerated. It is then reconverted to a vapor for burning in the engine.

LPG has been used as an internal combustion fuel since the mid-1920s. National standards for containers and pertinent equipment were first published in 1940 and have been continuously updated (*10*).

Reformulated Fuels

Fuel reformulation may include altering the composition of gasoline or diesel fuel to reduce sulfur and particulate content. There is significant potential for "clean" diesel fuel and for expanding the scope and performance of fuel mixtures, such as gasohol and M85. These alternatives are under study by petroleum companies and engine manufacturers. One large oil company predicts that clean diesel fuel will be readily available in time to meet the 1994 tail pipe standards for heavy trucks (A. Krodel, unpublished data, 1990).

Ethanol also has a role to play in the composition of reformulated gasoline. Octane levels in any reformulated gasoline must be kept high. Octane is a measure of the fuel's resistance to premature ignition, which causes spark-ignited engines to knock. Oil companies typically add oxygenates to fuels to raise octane levels. They are currently unable to meet Clean Air Act standards while keeping fuel octane ratings high using 100 percent petroleum-based ingredients. They can use a non-petroleum-based oxygenate in the form of ethanol, or ethyl tertiary butyl ether (ETBE). The other common oxygenate is methyl tertiary butyl ether (MTBE), a petrochemical made from methanol (*8*).

HANDLING PROPERTIES, HAZARDS, AND AVAILABILITY OF ALTERNATIVE FUELS

The handling characteristics of alternative fuels differ significantly from those of diesel fuel or gasoline, which is a major obstacle to their implementation. Clearly, conventional fuels have presented many safety problems, but they have been overcome in the last 130 years of petroleum experience. The automotive and petroleum industries developed appropriate infrastructure and safety precautions to deal with the dangers of conventional fuels (*11*). The leading alternative fuels, on the other hand, present different and challenging risks. Many of the differences in the handling properties of alternative fuels are due to their chemistry and physical properties.

Because gasoline and diesel fuel are molecular mixtures, their specific physical properties vary. For example, the boiling temperature of gasoline ranges from 80°F to 437°F. For diesel fuel the range is 370°F to 700°F. Diesel fuel contains approximately 18,000 Btu/lb and 130,000 Btu/gal, whereas gasoline contains about 18,000 Btu/lb and 115,000 Btu/gal (gasoline is less dense and, therefore, has fewer Btu per gallon than diesel fuel) (A. Krodel, unpublished data, 1990). Ethanol and methanol, on the other hand, are pure chemicals with fixed physical properties. The differences in chemistry and physical properties account for the different risks associated with transferring, dispensing, and handling alternative fuels.

Alternative fuel users also face the problem of supply. Availability largely depends on the manufacturing and distribution systems for fuels. Most transit systems do not depend on public commercial fueling sites, because they maintain their own refueling facilities. Use of even the leading alternative fuels is not widespread in fleet operations, so fuel supplies and vendors are, to varying degrees, limited.

Conventional fuels are available throughout the United States through a widespread system of pipelines, terminals, and delivery vehicles. The existing petroleum fuel distribution system delivers 110 billion gal of gasoline and 20 billion gal of diesel fuel for motor vehicle operation in the United States each year (A. Krodel, unpublished data, 1990). The conventional fuel distribution system does not lend itself to the distribution of alternative fuels. Alcohol fuels are corrosive and mix with water. Gaseous alternative fuels are not compatible with the existing liquid fuel distribution system. In addition, limited amounts of alternative fuels are available.

The following subsections discuss the handling properties, hazards, and availability for each of the leading alternative fuels. Each of the alternative fuels requires enhanced ventilation of maintenance workplaces compared with conventional fuels. The type and location of ventilation necessary varies with the fuel (some fuels produce vapors that settle in low places, whereas others are lighter than air). The last subsection deals with training requirements for mechanics and vehicle operators so that they can deal with the hazards and improve handling safety.

Methanol

Handling Properties and Hazards

Methanol is considered a fire hazard when exposed to sparks, heat, or flames. Ignition sources for methanol include sparks from shop equipment and even sparks from static electricity. Methanol vapor has a density 1.1 times that of air, so it settles in low-lying areas, such as maintenance pits. Work areas should be appropriately ventilated with mechanical systems to avoid concentrations of methanol fumes. At the same time, methanol is much less likely than gasoline to ignite in open air. In well-ventilated or open-air areas, the low volatility of methanol makes fires less likely (P. Machiele, paper presented to American Institute of Chemical Engineers, 1989).

The flash point of a flammable liquid is the lowest temperature at which sufficient vapors may form above a pool of that liquid to permit its ignition. The flash point of methanol is 52°F. Therefore, the flammability of outdoor methanol spills changes with the seasons; flammability is not a problem on cold winter days.

A pure methanol fire has low flame luminosity, making it difficult (at night) or impossible (in daylight) to see or even to estimate the size of the fire. This led to the development of the M85 blend. With M85, the flame is visible in broad daylight.

Disposable work rags and methanol-contaminated absorptive material may present a fire hazard and are regulated wastes. Unless laboratory test results indicate otherwise, they should be assumed to be hazardous (Resource Conservation and Recovery Act, 40 CFR 261.31 and 261.32). They must be stored in EPA-approved fire-resistant covered containers until transport, using the EPA Uniform Hazardous Waste Manifest, to an EPA-permitted disposal facility [29 CFR 1926.252(e)]. Reusable cloth rags sent to commercial laundries are apparently "unregulated," although transit operators should carefully consider the liability and ethical issues associated with laundering these rags (Iowa Waste Reduction Center, University of Northern Iowa, 1991).

A prime fire hazard of methanol-fueled vehicles may be ruptured fuel tanks resulting from vehicle collisions. To date, two such collisions and spills have been reported; neither caught fire. Methanol vehicle operators may want to consider carrying an on-board supply of vermiculite or other absorptive material, as well as an on-board fire extinguisher.

Methanol is considered to be a moderate explosion hazard. A mixture of methanol fuel vapor and air will auto-ignite at 725°F. Liquid methanol ignites if exposed to hot surfaces, such as hot engine exhaust manifolds and components exceeding 430°F (*12*).

Methanol storage and dispensing facilities present unique but not insurmountable challenges. Methanol is incompatible with and may react vigorously with strong oxidizing agents, such as nitrates, perchlorates, and sulfuric acid. In a maintenance facility, common oxidizing agents include battery acid in automotive batteries and (zinc) chromate primers. Chromium (chromate) plating baths, lawn fertilizers (nitrates), and common powdered lime are other examples of incompatible oxidizing materials. Therefore, methanol must be stored and dispensed in separate facilities.

Fiberglass, glass-lined, or stainless steel vessels, piping, and fittings must be used for methanol. Methanol is a solvent, and it may attack and corrode plastic, rubber, and coatings found in traditional fuel storage and dispensing equipment. It may react with or corrode aluminum metals, such as steel-aluminum fuel nozzles, generating hydrogen gas. Methanol may attack terneplate linings of fuel tanks, aluminum or zinc fuel pump and carburetor castings, and fuel line and fuel pump elastomers (*13*).

The threat of explosion and fire in fuel tanks is more significant for methanol than other fuels. Fuel tank explosion of methanol vapor-air mixtures is possible with air temperatures between 45°F and 110°F. In a "closed-air" environment, gasoline vapors are considered too rich to burn, and diesel fuel vapors are considered too lean to burn. The methanol fuel-air mixture in closed-air tanks is within its ignition limits. To explode, the mixture must first be exposed to an ignition source. Methanol in a closed tank should be considered an explosion hazard (*12*).

Storage tanks often include floating covers, or tanks with inert atmospheres that address the problem of surface accumulation of vapors. Both on-board fuel tanks and stationary fuel storage tanks may accumulate excess vapors, necessitating vapor recovery and return systems for all fuel transfers (*14*; P. Machiele, paper presented to American Institute of Chemical Engineers, 1989).

Methanol delivery systems that include a submersible pump are not appropriate because the pump becomes an ignition source. Therefore, facility space should be allocated for a traditional stand-alone pumping system (P. G. Saklas, unpublished data, 1989).

Vapors from methanol are toxic. A person who can smell methanol has probably been exposed to an unhealthy level. A brief whiff, however, is not considered harmful. The maximum airborne limit for methanol vapor, set forth by the U.S. Department of Labor's Occupational Safety and Health Administration (OSHA), is 200 ppm.

Methanol is a defatting agent. As such, exposed skin may become cracked and dry. Absorption may occur through the skin. Symptoms are similar to those of inhalation. The fuel is especially harmful to the mucous membranes. Methanol is a severe eye irritant, and continued exposure may cause eye lesions. In cases of dermal contact through the clothing, contaminated clothing should be removed immediately and the skin should be washed with soap and flushed with water for 15 min. Methanol is readily absorbed into the skin at a rate of about 0.2 $mg/cm^2/min$. Immersion of one's hand in methanol for 4 hr would permit sufficient absorption to cause death (P. Machiele, paper presented to American Institute of Chemical Engineers, 1989).

Clinical research to date has provided little information on methanol toxicity resulting from chronic, low-level outdoor exposure or exposure in well-ventilated areas (*13*). There are some standards set for chronic exposure. The American Council of Governmental Industrial Hygienists (ACGIH) in 1985 and the National Institute for Occupational Safety and Health (NIOSH) in 1976 established ambient air concentration threshold values for methanol vapor. The ACGIH threshold limit value (TLV) is 260 mg/m^3 time-weighted average (TWA) over 8 hr. Its 15-min TLV is 310 mg/m^3. NIOSH recommends a TWA standard of 260 mg/m^3 and a 15-min ceiling of 800 ppm.

The research on acute exposure to methanol is more complete. Toxicity from larger doses of methanol taken over a short time follows a well-known pattern. Symptoms include nausea, headaches, blurred vision, and an initial mild depression of the central nervous system. An asymptomatic period of several hours to several days usually follows. The latent period then gives way to physical symptoms, including metabolic acidosis and visual impairment or blindness. In severe cases, coma and death may follow (*15*).

Methanol is toxic if ingested or accidentally swallowed. Small amounts can intoxicate and cause blindness. The usual fatal dose is 3 to 4 teaspoonfuls. Methanol poisoning is treatable with prompt medical attention.

Long-term low-level exposure to methanol is not considered to pose chronic health problems. Methanol occurs naturally in the body at a level of about 0.5 mg/kg of body weight. It is also present in a daily diet of fruits, vegetables, alcoholic beverages, and aspartame, the diet soft drink sweetener (P. Machiele, paper presented to American Institute of Chemical Engineers, 1989).

Shop areas and refueling stations must have eye wash facilities and safety showers (*14*). It may be necessary to have a rest room or dressing room for workers handling methanol to ensure that contaminated clothing does not go home with the crew. Costs for installation of an eye wash and emergency shower (excluding drain facilities) have been estimated at $1,500 (*16*).

Spilled or leaking methanol may not be flushed to the public water treatment facility because of the potential for fire and explosion in the sewer lines and its structurally corrosive nature [40 CFR 403.5(b)]. Specially designed dedicated floor drains are advised for methanol shop and refueling areas. Traditional oil separators cannot be used, because methanol is miscible with water. Even mixtures of one part methanol to five parts water are flammable (*12*).

A by-product of methanol combustion is formaldehyde, which can cause a burning sensation in the eyes, nose, and throat. The highest concentrations of formaldehyde in methanol exhaust have been found during the first 8 min after start-up of a vehicle. This occurs because the catalyst is neither warmed up nor fully effective. It is, therefore, essential to cold-start methanol engines outdoors or in mechanically well-ventilated areas (*13*). There are currently no EPA standards for formaldehyde exposure (*17*).

Although methanol presents severe health hazards, when handled appropriately, it does not represent a significant safety threat. In 4 years of experience with methanol-powered buses purchased through UMTA's Methanol Bus Demonstration Program, no incidents have been reported in which transit workers were harmed (*18*).

Availability

Methanol has about 57,000 Btu/gal, or 43 percent of the energy content of diesel fuel. In January 1990 wholesale methanol fuel at Gulf Coast markets in the United States sold at between 36 and 38 cents per gallon (*19*). The price has decreased since 1988, when the cost ranged from 55 to 60 cents per gallon. Research indicates that at 55 cents per gallon, the methanol-equivalent of the energy in a gallon of diesel fuel would cost $1.22 (*20*).

Currently the annual world supply of methanol is roughly 7 billion gal (A. Krodel, unpublished data, 1990). The feedstock used to produce methanol is natural gas. Although the conversion process results in an energy-dense liquid, the process is only about 60 percent efficient (40 percent of the energy is lost during the conversion). Methanol can be produced from coal gasification and biomass, but their conversion to methanol is approximately twice as costly as the conversion of natural gas.

The manufacture of methanol could be increased, but there is no incentive to measurably expand supplies. Because methanol has less than half the energy density of conventional fuels, twice as many gallons of methanol would have to be produced as the amount of petroleum replaced.

Distribution and delivery systems for methanol present two challenges: methanol is corrosive and requires special storage and delivery equipment, such as dedicated tank trucks; and its toxicity requires special precautions and training for users and for those who service methanol vehicles.

CNG

Handling Properties and Hazards

Natural gas has been used as a vehicle fuel in the United States since the late 1960s. According to the Natural Gas Vehicle Coalition, there are currently between 250 and 300 CNG refueling sites across the nation, with about two dozen open to the public. Most refueling stations are open only to utility companies or private fleets.

Because of residential and industrial use of natural gas, it has its own distribution systems and supply network. The supply and distribution system of natural gas is superior to that of the other leading alternative fuels. Mechanics and operators are accustomed to its physical properties and risks. The most significant drawbacks of natural gas are (*a*) its low boiling point and (*b*) the requirement that to generate enough energy per volume of storage, it must be highly compressed (2,000 to 3,500 psi). Compression requires a great deal of gas, powerful, high-voltage compressors, and bulky vehicle tanks.

CNG ignites at temperatures between 1,200°F and 1,300°F, about twice as high as gasoline, so it is more difficult to ignite than gasoline. The higher heat at ignition presents problems in dissipating heat from CNG-powered heavy-duty engines. Natural gas will ignite only in a limited gas-to-oxygen mixture range of 5 to 15 percent (*21*). Because there is a moderate explosion risk with CNG, care should be taken to isolate and eliminate potential ignition sources. Natural gas is lighter than air, and any leaks disperse upward. This makes proper ceiling ventilation essential in vehicle maintenance shops.

According to National Fire Protection Association standards, gas compressors, dispensing equipment, and storage containers may be located inside or outside buildings. Most refueling activities are performed outdoors to prevent fire or explosion. It is unclear whether insurance underwriters, fire officials, and building code departments will allow indoor fueling of CNG equipment. A building separate from other activities (e.g., maintenance) should be used for indoor refueling facilities. In addition, specially constructed blowout wall panels are recommended for relief in the event of an explosion. Fire protection systems must be installed with densities and flow rates adequate for high-hazard uses (internal memorandum, New Jersey Transit Bus Operations, April 20, 1989).

The CNG facility must have an independent mechanical ventilation system, gas detection system, and explosion venting system. For fast-fill, high-horsepower compressors, the noise level is significant. Soundproofing, as well as high-voltage electrical service, are, therefore, necessary. In some locations, significant improvements by utility companies may be necessary to increase underground gas pipeline capacity (*22*).

Availability

The retail price for natural gas varies by location, from about 41 cents to 70 cents per therm. One therm is equal to 100,000 Btu, or roughly three-fourths the energy content of 1 gal of diesel fuel (*13*).

Natural gas is in plentiful supply, and most urban areas already have a distribution network. The primary drawback is that it occupies 1,000 times the volume of its energy equivalent in gasoline, thus creating the need for compressing natural gas in heavy tanks. On the average, the tanks plus the fuel in a CNG-fueled vehicle account for 36 percent of vehicle weight, compared with 11 percent for the average gasoline-fueled vehicle (*23*).

It is estimated that there are 30,000 to 40,000 CNG vehicles on the road today in the United States and some 700,000 worldwide (*24*). Most CNG vehicles in the United States are members of fleets. This is partially because of the expensive compressors, CNG storage tanks, and high-capacity gas supply lines required with fast-fill systems and the lengthy refueling with less expensive slow-fill systems. Fast-fill systems can refill roughly as quickly as for a refill of diesel fuel. Slow-fill systems are usually designed to refill vehicles when they are not being used (e.g., overnight).

Ethanol

Handling Properties and Hazards

Much like the other fuels, ethanol presents a fire hazard if handled improperly. The explosion hazard of ethanol when exposed to flames is rated moderate. Although ethanol is less volatile than gasoline, it is considered to be more explosive. Like methanol, vapors that form above a pool of ethanol are potentially explosive. Therefore, it must be stored in specially vented containers (*6*).

Repeated overexposure to ethanol will cause redness and irritation of the skin. Ethanol is not considered to be hazardous to the skin, but it is considered an eye hazard. Inhalation of small amounts of ethanol vapors is not considered to be toxic.

Excessive ingestion of ethanol is dangerous and requires gastric lavage, followed by saline catharsis and medical care. As an intoxicating beverage, ethanol presents a special supervisory challenge. Supplies of ethanol must be carefully monitored, and great care should be taken to determine that employees are not intoxicated on the job.

Small amounts of ethanol spills or leaks may be flushed with water. Large amounts should be contained and collected for incineration.

Availability

Grain-producing states from Indiana to western Nebraska have ample supplies of ethanol fuel. The supply and distribution channels in the New England, Southern, and Far West states are considered moderate.

Ethanol is produced from the distillation of grain products. The most commonly used grains are wheat, corn, and milo (grain sorghum). Alcohol is not manufactured or distilled directly from grain. Rather, there are at least two important extractive products that are manufactured before the distillation of alcohol.

First, the grain is milled and the protein is extracted. In the case of wheat, this produces vital wheat gluten, a high-protein food additive. This product is then sold, and the wheat starch remains. The starch is processed, the premium wheat starch is sold for human consumption, and other starch is sold for industrial purposes. The processing "leftovers" are then sent to a distillery, where alcohol is produced.

Once the alcohol is produced, it is refined. The purest grade is known as grain neutral spirits. This is the product used in the beverage industry and for chemical ethyl alcohol. The fuel-ethanol grade is just slightly lower in purity.

Companies selling both beverage-grade premium ethanol and fuel ethanol may use the fuel-ethanol market as an inventory-clearing tool. In this way, ethanol inventories can be controlled without dumping large quantities onto the higher-priced beverage alcohol markets, thereby risking a supply-sensitive price decline (interview with H. Hinton, May 7, 1990).

Ethanol has only about 76,000 Btu/gal, or 58 percent of the Btu energy per gallon of diesel fuel. In May 1990 fuel ethanol (200 proof) prices to retailers were $1.24 to $1.25 per gallon, FOB terminal, in the Omaha area. Wholesalers paid $1.13 to $1.14 per gallon, FOB terminal, for ethanol directly from an Atchison, Kansas, plant (price quotes from Midwest Grain Products).

The price of ethanol varies significantly on the basis of geographical region and subsidy levels. The wholesale price of 200-proof ethanol in January 1990 was between $1.10 and $1.36 per gallon (*25*). Ethanol has sold for as much as $3 per gallon (*13*).

Almost 1 billion gal of ethanol is currently used as motor fuel and in reformulated fuel (gasohol). Ethanol has slightly more than half the energy density of conventional fuels (i.e., gasoline and diesel fuel). Thus, to replace conventional fuels would require slightly less than twice the volume of ethanol. Producing substantially more ethanol will tremendously tax the agricultural sector. For example, it is estimated that to double United States ethanol fuel production (to roughly 1.82

billion gal) would require an additional 715 million bushels of corn annually (*26*). In 1985 the entire corn crop of Iowa, which produces more corn than any other state, was only 1,707 million bushels (*27*). Ethanol production cannot be directly related to corn production, because ethanol is only one of the products from grain processing, and additional grain by-products would be used to produce other goods. This indicates that the use of ethanol as a motor fuel for any significant share of the demand for transportation energy would overwhelm the agricultural sector.

LPG

Handling Properties and Hazards

Heavy fuel tanks are required to contain this moderately compressed gas. LPG fuel systems are pressurized to about 250 psi, often 175 psi. Many fuel tanks, however, are built with ¼-in. steel, to a 1,000-psi specification. This makes them much more capable of withstanding a collision than typical gasoline or diesel tanks.

There is also a combustion hazard with the use of LPG, which can be minimized by eliminating ignition sources and performing refueling and maintenance activities outdoors where possible. Direct heat applied to storage or vehicle fuel tanks is dangerous, because temperature changes may cause pressure changes inside the tanks, with a potential for explosion.

Many organizations that handle propane use portable explosion meters that detect unacceptable levels of ambient propane. Many fire departments have not invested in explosion meters. It is recommended that fleet operators making extensive use of propane fuel purchase their own meters.

In gaseous form, propane is heavier than air, so it tends to settle in trenches or maintenance pits, exacerbating the explosion hazard there.

For safety reasons, most propane tanks are designed to be filled to about 85 percent of capacity. As long as the sealed pumping system operates without leaks, the risk of explosion is low.

Propane boils at −44°F. There is a burn risk when opening valves to bleed off excess propane remaining in the line after refueling or fuel transfer. The amount remaining in the line is typically about 1 tablespoon. Heavy insulated neoprene gloves should be required for persons engaged in fuel transfer activities.

Small amounts of propane leaking into the air disperse. It is recommended that all maintenance areas be well ventilated. Propane is not known to be toxic.

Technical regulations and recommendations for the safe use of LPG have been well developed over time. A discussion of standards for containers, installations, valves, cylinders, vaporizers, piping, and other items may be found elsewhere (*28*).

Availability

The principal vehicle fuel application of LPG is propane gas. Propane sells for 30 to 40 cents per gallon at the wholesale level and 40 to 50 cents per gallon retail. Many prices are quoted at Conway, Texas. For terminal delivery, another 4 cents per gallon should be added for pipeline and truck transport cost (interview with Campbell Oil Co., 1990). The typical 91,000-Btu/gal propane offers between 71 and 83 percent of the energy content of diesel fuel.

LPG is a by-product of petroleum refining. Although LPG has desirable properties for reducing vehicle emissions, its use does not reduce the dependence of transportation on petroleum-based fuels.

There are approximately 330,000 LPG-fueled vehicles in the United States and more than 2.5 million worldwide (*29*). The LPG transportation fuel market in the United States could grow to 2.85 million to 3.6 million vehicles by 2004 (*29*). Because it is a by-product of petroleum production, increases in production of LPG are governed by the refining of other petroleum products. LPG can be easily transferred to vehicles at rates rivaling the refueling of conventionally fueled vehicles, at 12 to 15 gal/min.

Workplace Training Programs

Effective training programs are essential to the success of an alternative-fuel program. Training should encompass all aspects of any alternative fuel in use, including a general description of the fuel, examples of its uses both in engine applications and elsewhere, and its toxicity and hazards. Relating case studies on toxic ingestion, skin absorption, fire hazards, and explosion risks may be helpful.

Training in hazardous materials or wastes should be conducted pursuant to the 1983 OSHA Hazard Communication Rule, also known as the "Right To Know" law, as amended (29 CFR 1926.59). Many states have similar rules. The law requires the development and maintenance of a written hazard communication program in workplaces. Steps to be taken include developing a list of hazardous substances, placing proper labels on containers, keeping Material Safety Data Sheets for employee use, and establishing training programs for protective measures. Specific protective eye wear, head gear, and respiratory protection devices are outlined (29 CFR 1926.100 through 1926.103).

Alternative-fuel pumping devices take longer to fill the vehicle's tank than gasoline or diesel fuel. For gaseous fuels, fast-fill equipment may reduce fueling time. Refueling takes longer for methanol and ethanol because they have less energy content per unit volume than diesel fuel. With additional safety and fuel security devices in operation at the time of fueling, crews should expect a different pace of work.

Some transit authorities, such as the New York City Transit Authority, issue certificates of fitness to employees trained in and authorized to handle alternative fuels. Certificates are earned through successful completion of a practical training program. This ensures an emphasis on learning and safety awareness on the job.

Other specialized training that should be considered for maintenance, refueling attendants, and drivers includes firefighting techniques, use of protective clothing and equipment, and fuel inventory practices.

CONCLUSIONS

Each of the leading alternative fuels has significant impediments to widespread implementation. Because of supply, handling, and distribution problems and costs, alternative fuels are likely to be integrated in and have their greatest impact on transit fleets and other self-fueling fleets. Many of the anticipated drawbacks, especially health hazards, have not been a significant impediment to use by fleet operators. Experiments to date, however, are probably not indicative of ordinary use. They suggest that, given the correct precautions and worker training, it is possible to overcome the challenges to fleet integration and work safely with different and hazardous fuels such as methanol in the transit industry.

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Development of Private Services at Park-and-Ride Lots in Central Puget Sound

G. Scott Rutherford, Lawrence D. Frank, and Andrea F. Tull

The provision of a variety of private services, such as convenience markets, dry cleaners, video stores, and day care, at existing and proposed park-and-ride lots was investigated. Institutional and legal issues were studied and found not to pose insurmountable problems. However, they make development of new sites more attractive than development at existing park-and-ride lots. A process was created to assess the potential for development at nearly 100 sites in the Seattle area. An increasingly detailed evaluation process resulted in the selection of five case study sites—two proposed sites and three existing park-and-ride lots. A discussion of market and site requirements for retail development is included. It was concluded that private development of park-and-ride lots can help enhance patronage and rider satisfaction, provide lot security, and generate revenue for transit purposes.

The transit industry must compete with a form of transportation that provides wide-ranging mobility. U.S. society, with its many two-income households, demands timeliness and convenience to squeeze an increasing number of activities into a day. Combining secondary trips with the morning and evening commute is necessary to drop off and pick up children, shop, and run other errands. These secondary trips occur at the worst possible time for traffic conditions, and ways to mitigate them are needed.

Transit is not currently a competitive service for most secondary trips unless they are made with an automobile as part of a park-and-ride trip. For low-density suburban development, collection of transit patrons at park-and-ride lots has become an economic necessity. To reduce secondary trips, provide on-site convenience, and enhance security, many services could be jointly developed with park-and-ride lots to serve the lot patrons and general public alike. The services might include convenience stores, gas stations, video renters, carryout restaurants, cleaners, and day-care centers. Figure 1 shows a concept plan of a typical development.

To investigate the feasibility of retail and other services located at park-and-ride lots, a study was undertaken by the Washington State Transportation Center and the Municipality of Metropolitan Seattle (Metro). The study was funded by UMTA, the Washington State Department of Transportation (WSDOT), and Metro (*1*). The study was divided into segments as shown in Figure 2. The structure and significance of each phase are discussed below.

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LITERATURE REVIEW AND INSTITUTIONAL AND LEGAL ANALYSIS

Literature Review

The initial phase of the study involved an analysis of several associated bodies of knowledge. For the purposes of this study, they were divided as follows:

- Park-and-ride lots;
- Joint development;
- Transit patron distribution and collection;
- Land use opportunities and constraints;
- Site planning, circulation, and design; and
- Barriers to private activities.

The focus was on past joint development experiences and park-and-ride lot development. Also reviewed were transit infrastructure financing techniques, private-sector perspectives on joint development, surface transportation connections, land use factors, site planning and design, and barriers to private activities. The general findings from the literature search included the following:

- Little experience in the joint development of park-and-ride lots exists in the United States.
- Several obstacles minimize the attractiveness of joint development for both the private and the public sectors. For the private sector, the time frame for return on investment is much shorter than for the public sector. The public sector is primarily discouraged by the risks associated with market failure of the private services and lack of knowledge about commercial operations.
- The location of services at facilities surrounded by office developments may result in a mixed-use effect, reducing midday trips. However, few park-and-ride lots are located near office complexes.

Concurrent with the literature review, the institutional and legal issues involved in joint development of park-and-ride lots were investigated.

Institutional and Legal Analysis

Private development at park-and-ride lots can present difficult institutional issues because several agencies may participate

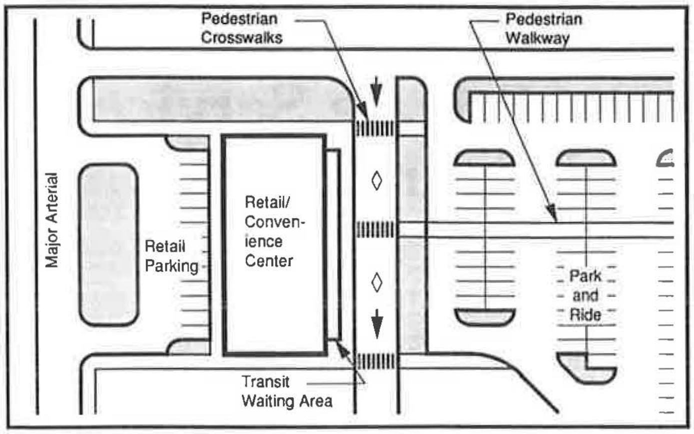

FIGURE 1 Typical park-and-ride retail development.

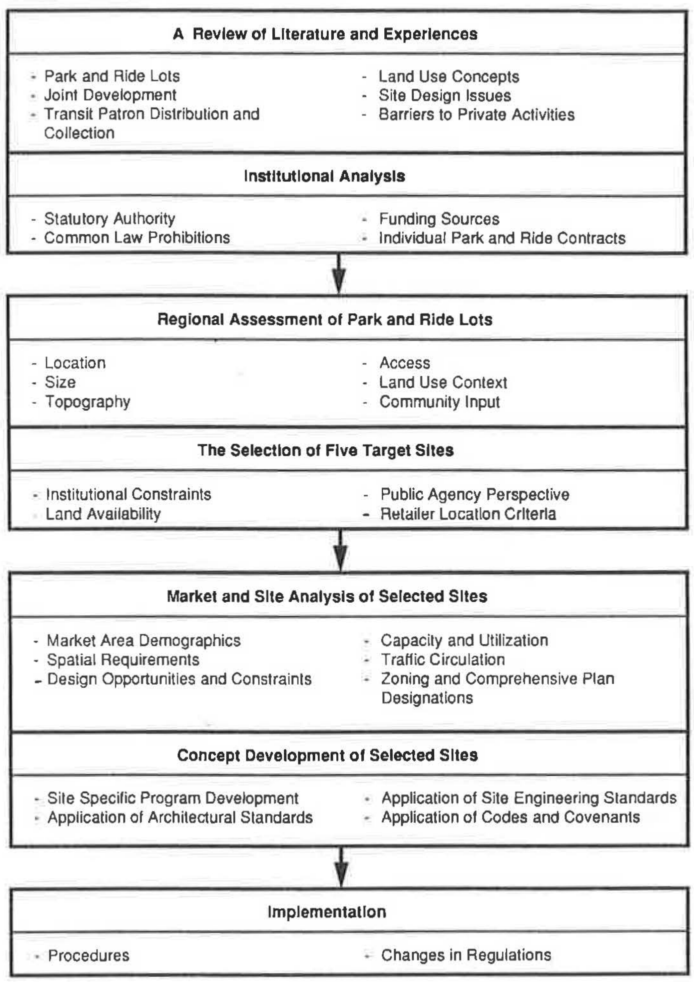

FIGURE 2 Research design.

in funding various aspects of the lot. It was found that potential restrictions on private development may arise from statutory authority; common law prohibitions; federal or state funding source statutes, regulations, and guidelines; and individual park-and-ride contracts with funding agencies.

Transit agencies will find joint development difficult without title to park-and-ride land. Each affected funding organization has its own restrictions and rules regarding the secondary use of land it has funded for park-and-ride development, but each appears to allow private development as long as its policies are followed.

Ownership

If a transit agency holds the title to a park-and-ride lot, it has a great deal of latitude concerning joint development on the property because it is subject only to its own statutory requirements and common law constraints. Transit agencies in the Seattle area are allowed to lease their park-and-ride property for private commercial uses. However, the use must be consistent with the public transportation purposes for which the property was acquired, and the property must be surplus and must not be needed for public transit purposes during the life of the joint development project.

Transit agencies usually do not own park-and-ride property. Most park-and-ride lots in the central Puget Sound area have been funded with federal or state funds or a combination of the two. This situation is true for most park-and-ride lots at transit agencies across the country, and it makes joint development more difficult.

Transit agencies may regulate certain activities at park-and-ride lots, and the prohibition of these activities may inhibit development. Examples of prohibited uses include food and beverage services, vehicle maintenance, and recycling.

UMTA Funding

The key to a successful joint development project from UMTA's perspective is that the secondary use be beneficial yet "incidental" to the facility's transportation function. For UMTA to consider the use incidental, it must be compatible with the approved purposes of the park-and-ride and not interfere with the intended function of the facility. UMTA encourages incidental uses of real property that can raise additional revenues for the transit system or, at a reasonable marginal cost, enhance system ridership. According to UMTA officials, important factors in the approval of a private-sector development project as an incidental use include the following: (*a*) how long the private development will occupy park-and-ride property; (*b*) the space occupied by the private development project relative to the space available to park-and-ride parking; (*c*) the nature of any interference with the primary transit benefits of the park-and-ride lot; and (*d*) the transit benefits of the private development project, either in additional revenues for the transit system or enhanced ridership.

Representatives from UMTA stressed that joint development proposals are reviewed on a case-by-case basis and that no clear line can be drawn between proposals that are approved and those that are rejected. Therefore, transit agencies need to give special attention to the incidental use requirement and clearly describe the benefits to transit users. UMTA regulations preclude the use of Section 3 (Capital Grant) funds for construction of commercial revenue-producing facilities, whether publicly or privately owned.

If a proposal for a joint development project is not approved, the transit agency has several options. The proposal may be revised, if possible, to meet UMTA objections and then resubmitted. If the transit agency wants to pursue the project as planned, it can determine that the property under consideration is surplus. The property must be sold at fair market value, and UMTA must be reimbursed for the percentage of the property that it owns. This alternative allows the project to proceed, but it eliminates any monetary benefit to the transit agency. However, it provides some benefit to transit users because of the retail services to be provided at the park-and-ride, and it increases the attractiveness of the park-and-ride.

FHWA Funding

If funds from FHWA were used to purchase park-and-ride property, its policies concerning the use of the property and associated revenue must be followed. FHWA dispenses its funds through the state departments of transportation for highway projects. Transit agencies must first apply for approval of a joint development project through their state department of transportation, which will forward the proposal to FHWA. FHWA considers park-and-ride lots to be highway projects, and the lots are covered by the same policies.

FHWA must approve a transit agency's proposal for joint development before any property rights are conveyed to the developer. If a joint development proposal is approved, the transit agency must charge at least fair market value for the sale, use, or lease of the property, with an exception granted for social, environmental, or economic mitigation purposes. The exception allows the transit agency to provide leased space at the park-and-ride at the best rate it can obtain if fair market value cannot be achieved. The exception may also include socially beneficial uses, such as a day-care center, at a rate below fair market value.

The federal share of net income (gross income minus operating expenses) is based on the participation ratio each state uses in claiming reimbursement for acquisition if federal funds were used to help construct the park-and-ride project. These funds must be used as a direct credit to other projects eligible for federal highway grants, such as additional park-and-ride spaces, and cannot be used to cover operating expenses. Each state department of transportation must approve this process and the project to receive the revenue from the joint development.

FHWA has no written criteria for evaluating private development projects at FHWA-funded park-and-ride lots. In practice, though, the criteria appear to be similar to those of UMTA.

As with UMTA, if the proposed project is not approved by FHWA, the transit agency may resubmit the proposal with the requested modifications or declare the property to be surplus. If the property is declared to be surplus, the transit agency must compensate FHWA for its share. The transit agency must reimburse FHWA up front, as in the case of UMTA. Once it has reimbursed FHWA, the transit agency is limited only by its statutory powers and by any common law prohibitions against proprietary activities by governmental agencies.

State Ownership

If funds from a state department of transportation have been used for a park-and-ride, approval for a joint development project must be obtained from the state department of transportation. WSDOT grants approvals for joint development projects on a case-by-case basis. Among the requirements for approval are that the sale or lease be based on the fair market value of the property, that no net loss of parking spaces occur at the park-and-ride lot, and that the commercial development not interfere with transit purposes.

WSDOT has the authority to lease or sell unnecessary highway land or air space, including park-and-ride lot property, provided that the property is no longer required for highway purposes and that it is in the public interest to do so. WSDOT may look favorably on property exchanges between the state and private entities involving park-and-ride lots if the public benefits, especially in additional park-and-ride space. WSDOT will only approve the sale of park-and-ride properties to private entities when it is clear that the properties will no longer be needed for transportation purposes.

PROCEDURES: ANALYSIS OF PARK-AND-RIDE LOT DEVELOPMENT POTENTIAL

Site Inventory

A preliminary assessment of development potential began with a complete list of park-and-ride lots in the Seattle area. The list was reviewed to eliminate sites that would be inappropriate for joint development. As a result, leased lots and lots under 50 stalls were eliminated from further consideration. The locations of regional lots are shown in Figure 3.

The same characteristics that make a site attractive as a park-and-ride lot, such as good location, visibility, size, and access, also make the site attractive for private commercial development. Table 1 gives some of the locational criteria for park-and-ride lots and retail space. There is a significant degree of overlap in the criteria for the two uses. However, whereas a site may be attractive for development, the transit function remains the paramount purpose of the park-and-ride system. Ways were analyzed to supplement the supply of park-and-ride spaces through a variety of joint development methods, such as potential land trades, shared parking with adjacent businesses, on-site retail development, and commercial development at sites adjacent to the facilities. If a park-and-ride lot was at or near capacity, spaces could not be eliminated to allow for joint development, even though the lot may have been otherwise ideal. In such a case, air rights development (if feasible) or land trades for larger, more suitable nearby sites were considered.

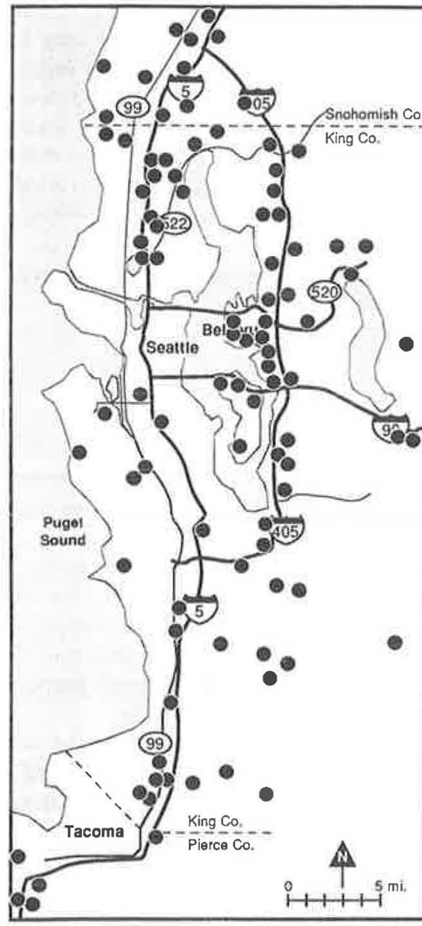

FIGURE 3 Location of park-and-ride lots.

TABLE 1 CRITERIA FOR THE LOCATION OF PARK-AND-RIDE LOTS AND RETAIL SERVICE DEVELOPMENT

	Park-and-Ride	Retail Space
Distance to Downtown	•	
Access to Freeway	•	•
Local Demographics	•	•
Freeway Congestion	•	
HOV Lanes	•	
Arterial Volume	•	•
Other P&R Lots	•	
Other Retail Space		•
Visibility from Freeway and Arterial	•	•
Land Use and Zoning	•	•
Catchment Area for Arterial Traffic	•	•
Institutional Issues	•	•
Development Interest	•	•

Evaluation Process

On the basis of the data gathered on the park-and-ride sites, pictures and videotapes, and the research staff's impressions, the joint development potential of the lots was assessed. To narrow the list of park-and-ride sites to be considered for joint development, the sites were categorized into those with high, moderate, and limited potential.

Sites with high potential met the criteria of adequate space for surface or air rights development, good visibility, good access from major arterials or freeways, and desirable locations. In addition, these sites were attractive because of the caliber of adjacent development or the character of the surrounding area.

Sites with moderate potential offered a mix of the characteristics of the high-potential sites but not to the same degree. Moderate-potential sites presented more challenges to joint development than did the high-potential sites.

Sites with limited potential were either fully utilized with no possibility of expansion or lacked many of the characteristics necessary for consideration of joint development. However, some of the low-potential sites were possible locations for mobile services such as espresso stands or pick up–drop off dry cleaning service.

The initial evaluation placed 50 lots in the categories of high, moderate, or limited potential for joint development. The other 40 sites were mostly leased space, which greatly reduced or eliminated their potential. The initial information was used for a more detailed analysis of these sites' market potential for joint development.

Retail Market Feasibility

The assessment of the high-potential candidates was based on an analysis of retail market feasibility from a developer's perspective. The following methodology was developed and used as a guideline for assessing the potential development sites. The primary question was whether a retail developer could be attracted to a high-potential location. From a developer's perspective, the key factor encouraging development is the ability to profitably attract tenants. To attract them, both developer and tenant must believe that sufficient surrounding trade area demand exists to support the risk of achieving profitability. Retail market analysis gauges trade area demand and thus profitability.

Typically, retail market analysis methodology encompasses the following steps (*2*).

1. Evaluate the site as a retail location. Frontage on a major arterial is of primary importance.
2. Establish an effective trade area. Transit patrons will not provide the primary demand; therefore, relationship to available retail outlets is important.
3. Analyze trade area population and buying power. Age and income of the population in the trade area determine buying power.
4. Determine retail customer expenditure potentials within the trade area. Projections of expenditures by type of good or service help assess the market for particular stores.
5. Assess trade area retail competition. The ability of the market to sustain more retail must be determined.
6. Forecast market penetration and retail sales volume at the subject site. With the preceding information, plus information about future development, the market share for a given retail outlet is forecast.
7. Determine the mix and square feet of retail space market supportable at the subject site. This is used in discussions with possible tenants.

Each of these seven steps was used to develop a short list of existing and proposed park-and-ride lots that would be good development candidates.

Retail Compatibility—Physical Design Criteria

Other site-specific information was used in the analysis, including available space, land use and political constraints, institutional constraints, and circulation.

Available Space Most existing park-and-ride sites were designed to maximize the capacity of the site. For this reason, they often contained little or no undeveloped land (at grade) suitable for retail space. Exceptions to this constraint included air space development where economically and institutionally feasible, topographic opportunities such as slopes, and sites in the planning phases of development.

Land Use and Political Constraints Some sites were located in areas that had incompatible adjacent land uses for certain joint development purposes. An example of this constraint is the location of a park-and-ride facility in an area of single-family housing. Inhabitants of such an area may oppose certain retail uses at the park-and-ride facility and may be organized well enough to block development. Environmental sensitivity and issues of zoning conformance were also analyzed at the high-potential sites.

Institutional Constraints Several institutional constraints governed the use of park-and-ride lots owned or funded by UMTA, FHWA, and, in this case study, WSDOT. The regulation that most restricted the development of a nontransit public benefit use was that against reducing the number of parking spaces.

Circulation Access to the site from a variety of modes was analyzed. Turning movements onto sites, levels of service of adjacent intersections, and congestion levels of roads around the sites were analyzed. Pedestrian and other nonvehicular linkages to the site were viewed favorably.

THE FIVE CASE STUDY SITES

The selection of the following five sites for a more detailed analysis of joint development potential was based on the foregoing criteria. The retail market potential, in conjunction with the physical constraints of each potential site, was analyzed. The three existing sites selected were Woodinville, South Bellevue, and Eastgate. The two proposed sites selected were the northwest quadrant of 164th Street and I-5 in Snohomish County and the southwest quadrant of 54th Avenue and 20th Street in Fife, Pierce County (see Figure 4).

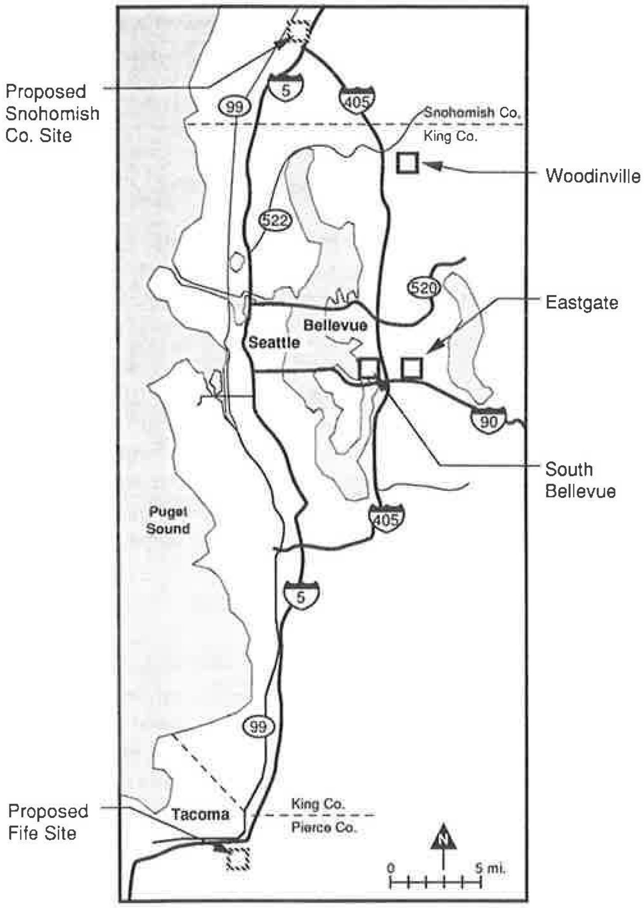

FIGURE 4 Location of five target sites.

Woodinville—Woodinville-Duvall Road–140th N.E.

This location was chosen because space was available for development without taking parking spaces away from the lot. Adjacent land uses were also supportive of joint development.

South Bellevue—Bellevue Way–112th S.E.

Reasons for selection included easy access to the rapidly developing I-90 corridor, adjacent land use (Mercer Slough Park), conduciveness to day care, and minimal vehicle-pedestrian conflicts.

Eastgate—S.W. Eastgate Way–136th S.E.

The proximity and ease of access of this site to major retail and service concentrations made it an excellent candidate for a mobile services vendor. Adjacent land use, which was office and commercial, offered market potential for any services located on this site.

Snohomish County—Northwest Quadrant of 164th Street and I-5

During the study, this project was in the planning phases. It was selected on the basis of visibility from 164th Street, frontage along 164th Street, market potential from the trade area to the west, limited convenience competition in the trade area (west of I-5), and the ability to properly plan the site to incorporate retail requirements.

Fife—Southwest Corner of 54th Avenue and 20th Street, Paralleling I-5

The reasons for selection of this undeveloped site included the benefits of planning for joint development in the development phases, reasonable access to I-5, projected demand, supporting adjacent land uses, visibility of the site, excellent frontage, and sufficient space.

MARKET AND SITE ANALYSIS

Once the study sites had been selected, their potential to support joint development could be determined.

The analysis of convenience and retail services focused on site selection criteria from the perspectives of developers and private store operators. The intent was to demonstrate to transit decision makers the locational, market, and financial criteria that the private sector requires to develop retail outlets or offer off-site services from a park-and-ride lot.

The analysis of each site included a survey of on-site features, such as topography and slope, and off-site features, such as adjacent land uses. In addition, the institutional and political constraints of each site were analyzed. The site analysis and land use study was presented in graphic form on a scaled plan of the site that included adjacent land uses. By conducting the two analyses in tandem, the study team could better match services to sites.

Analysis of Selected Convenience and Retail Services

The selection of services presented in the analysis was based on community input and recommendations made by a real estate development consultant. The services included day care, convenience stores, automotive service and lube centers, mobile services, and concierge services.

On-Site Day-Care Centers

The demand for proprietary day care greatly exceeds supply nationwide. Social trends underlie this condition.

Proprietary child care facilities were the focus of this project. Such facilities are normally designed for infants, toddlers, preschoolers, kindergartners, and year-round (before and after school and during the summer) elementary school children. Services offered include exercise, supervised play, reading, introduction to computers, field trips, evening care, drop-in hourly care, and transportation to and from elementary schools.

Proprietary day-care centers do not necessarily require direct frontage on major arterials. Exposure is not as critical as it is for most other retail and service businesses. Area parents quickly find day-care centers. Thus, day care could be placed toward the rear of park-and-ride lots, where land costs are less, noise and air pollution are low, and site exposure is already high because of the lot.

The maximum trade area radius for a proprietary day-care site is normally about 3 mi. Nationally, research indicates that most parents reside within a 2-mi radius of the day-care center they patronize. Preschool children typically are drawn from further distances than elementary school children (*2*). The dual purpose accomplished by locating day care at park-and-ride lots would probably result in increasing the trade area size above these national norms.

Interviews with multistate day-care center developers indicate that exploring the concept of locating day-care centers on certain Seattle area park-and-ride lots would be of interest. The idea fits their current pursuit of new market segments requiring day-care services.

Proprietary day-care developers usually seek a trade area with a radius of approximately 3 mi and containing 25,000 to 30,000 people. However, a 50,000-person trade area population is preferable. Exceptions to this criterion are often made if an area is growing quickly. In certain rapidly growing areas, an existing population of only 15,000 within a 3-mi radius has been acceptable (*2*).

On the basis of interviews with multistate day-care center developers, it is estimated that the minimum land requirement for a day-care center at a park-and-ride lot is 18,000 ft^2. Typically, a 30,000 ft^2-site is required once setback, landscaping, parking, play area, and building site requirements have been met (*2*).

Day-care center prototype buildings run about 6,200 to 6,700 ft^2. Typical dimensions are 110 $\times$ 61 ft. The buildings usually accommodate from 100 to 125 children. Play areas are often about 10,000 ft^2. Parking requirements usually are one stall per employee, or four or five stalls (*2*). Extensive parking facilities are not necessary because parents usually park briefly to drop off and pick up their children.

The typical cost of a proprietary day-care building is about \$325,000, or approximately \$48/ft^2. Site costs usually run between \$100,000 and \$150,000, including site work (*2*). Day-care center developers at park-and-ride lots could mitigate such land costs if they were willing to sign ground leases with the transit authority.

Convenience Stores

The convenience store concept focuses on satisfying the majority of food and nonfood purchase requirements of consumers who desire quick, nearby service any time of day, every day of the year. Typically, two-thirds of the customers of a convenience store have been patronizing it for more than 1 year. In descending order of importance, customer reasons for shopping at convenience stores are (*a*) fast service, (*b*) nearness to home or work, (*c*) availability early and late hours, (*d*) friendliness of staff, (*e*) gas prices, and (*f*) other.

Gasoline sales, which typically make up about 60 percent of total sales, usually accompany merchandise sales at convenience stores. Offering gasoline is one way to attract customers into the store. Obviously, the acceptability of gasoline sales on park-and-ride sites could be an important issue for transit authority decision makers.

Economic success depends on locating a clean, neat, and bright store building on a well-traveled street. Excellent exposure and site egress and ingress are critical to economic success. A high-traffic corner location offering unobstructed turning movements is preferred. Highly visible signage is a must. Convenience store sites must be surrounded by a residential trade area with sufficient buying power to achieve a profitable sales per square foot performance level, roughly \$250/ft^2 annually. The trade area radius for convenience stores is typically 2 to 3 mi. However, more than half of total sales volume usually comes from residents living within 1 mi of the store. Usually 85 percent of customers travel to convenience stores by automobile (*2*).

Typical lot size requirements for a convenience store range from 12,000 to 18,000 ft^2. The accompanying asphalt parking area needs to be large enough to accommodate 10 to 13 cars. Convenience store buildings are usually about 2,400 ft^2 (*2*).

Security is a major issue associated with the private development of park-and-ride sites. The presence of services on and adjacent to park-and-ride facilities may well provide a strong deterrent to vandalism. The selection of quality private services is essential to the achievement of this objective.

Automotive Lube Centers

Competition for the automotive lube customer is keen. New car dealers are aggressively marketing to the oil change customer. Dealerships are encouraging lube and oil service when customers return their vehicles for warranty and repair work. Repeat customer business is cultivated at automotive lube centers. Follow-up service reminders are often sent to customers, and coupon specials are an added incentive to return.

High traffic counts and a highly visible location are a must in this business. Any site that has even moderate real or perceived access impediments will be rejected. A reason for this site location sensitivity is that many oil changes occur on "driver impulse." Lube center services must therefore appear quick, convenient, and not out of the way.

The trade area goal for lube centers is 75,000 motor vehicle registrations within a 3-mi radius. Although lube stores open in 3-mi-radius trade areas of 50,000 vehicle registrations, the competition that rapidly follows means that someone will probably not survive (*2*). In addition, locations on the periphery of the central business district adjacent to high concentrations of daytime employees are desirable.

The motor vehicle registrations count is critically important. Profitability typically depends on attracting from 30 to 50 lube and oil change customers per day to break even. The market target is 55 (*2*). The number of lubes per day required to break even mainly depends on land and building costs and on variable real estate tax and insurance expenses.

An automotive lube center absorbs about ½ acre of land. The minimum land area requirement is 18,000 ft^2, including a stacking and turning area for at least 12 cars. A typical automotive lube center building is 5,000 ft^2 (50 × 100 ft) (*2*).

Mobile Services

The idea behind this concept is for a vendor to sell coffee, juices, soft drinks, pastries, tickets, books, or papers from a mobile vehicle that services park-and-ride users during peak morning hours. Market support for this concept at park-and-ride lots is unproven in the Seattle area. The level of services could range from a mobile food van that makes a target park-and-ride site one of several stops on its daily route to development of a coffee and pastry kiosk on particular sites.

Concierge Services

The location of concierge services at selected park-and-ride sites might satisfy key public and private goals. Transit authorities could increase ridership and create public goodwill by offering convenient services for commuters at target park-and-ride locations. Private-sector profit potential exists for a skillfully managed concierge service at target park-and-ride lots.

A park-and-ride lot concierge service would operate as follows. A menu of services would be offered to commuters at an on-site concierge facility. Usually these services could be accomplished during the business day, perhaps by the concierge during the "off" hours of transit (i.e., 10 a.m. to 3 p.m.). The services could include dry cleaning and alterations, shoe repair, car detailing, automobile servicing, flower and balloon sales, entertainment ticket sales, travel services, video, film processing, personalized shopping, gift wrapping and shipping, company party arrangements, reminder services, search and quote services, house and yard cleaning, goods returned to retail stores, and courier services. No precedent exists for developing the concierge concept at park-and-ride lots in the Seattle area. Moreover, little joint development experience of similar concepts exists nationwide, except for one unsatisfactory experience in Houston.

The concierge service business is a personal relationship business. Operations at a particular location are not likely to stabilize until the service has operated for about 3 years. Experience indicates that the business builds slowly. Customers must both become familiar with the services and learn to trust the concierge operator. Repeat customer patronage patterns must be established.

Interviews with concierge service operators indicate that the park-and-ride lot concierge facility could be integrated into an enclosed waiting area for riders. The use of a movable unit that could be towed to the site was considered less desirable. The enclosed waiting area and concierge facility should be built and owned by the transit authority, and the concierge space should be leased to the private operator. Quality signage should be permitted to clearly communicate to riders the concierge services available. The concierge service should be high profile to attract transit riders to patronize the concierge service and to facilitate security of the operation and the park-and-ride lot.

The concierge operator would develop contractual agreements with various vendors in the trade area surrounding the park-and-ride site. Payment would be collected for the particular service by the concierge who, in turn, would pay the service providers, minus a percentage of the gross sale. The concierge operator would be required to carry appropriate insurance. An arbitrator for disputes might also be appointed.

The concierge service concept appears workable. Transit ridership should be enhanced because of time-saving services offered at park-and-ride lots that would make life easier for commuters. The risk of failure could be mitigated because the enclosed transit waiting area containing the concierge service could easily revert to a rider waiting area.

Table 2 summarizes the information given in this section and provides requirements for other services.

Site and Market Analysis

Only two of the project's five case studies will be presented here. Though it would be difficult to identify either of these as typical, they represent a range of possibilities. The sites presented are South Bellevue and 164th and I-5 (see Figure 4). Site design criteria drew heavily on other sources (*3–11*).

South Bellevue

The site and its characteristics are shown in Figure 5. Important considerations are as follows: the site is partially located in a designated sensitive area and is surrounded by a planned regional park, an interpretive center and farmers' market are being proposed south of the site as part of the

TABLE 2 POTENTIAL SERVICES AT PARK-AND-RIDE LOTS—MINIMUM SPACE NEEDS

Use	Minimum Requirements
Day care	PR-5 stalls, 18,000 sq. ft. lot, 6,200 sq. ft. facility
Convenience store/ Mini-mart	PR-10 stalls, 12,000 sq. ft. lot, 2,400 sq. ft. facility, FR
General auto service	FR-100', PR, 14,000 sq. ft. lot, 5,100 sq. ft. facility
Auto lube center	FR, PR-12 stalls, 18,000 sq. ft. lot, 5,000 sq. ft. Facility
Auto parts center	4,000 sq. ft., FR, PR
Florist Stand	200 sq. ft., MS, FR, PR
Dry cleaner/tailor	400 sq. ft., FR, PR
Video rental	200 sq. ft., MS, FR, PR
Newspaper/magazine vendor	800 sq. ft., MS, FR, PR
Take-out food	1,200 sq. ft., FR,PR
Coffee/pastry vendor	400 sq. ft., MS
Bagel/donut shop	600 sq. ft., MS, FR, PR
Fax/copy center	1,200 sq. ft., FR, PR
Shoe repair	400 sq. ft., FR, PR
Pharmacy	1,200 sq. ft., FR, PR
Film processing	200 sq. ft., MS, FR, PR
Package delivery	1,200 sq. ft., FR, PR
Mobile library	200 sq. ft., MS
Postal contract station	200 sq. ft., FR, PR

Key:	Symbol	Description
	FR	frontage requirement
	MS	potentially a mobile service
	PR	parking needs to be provided

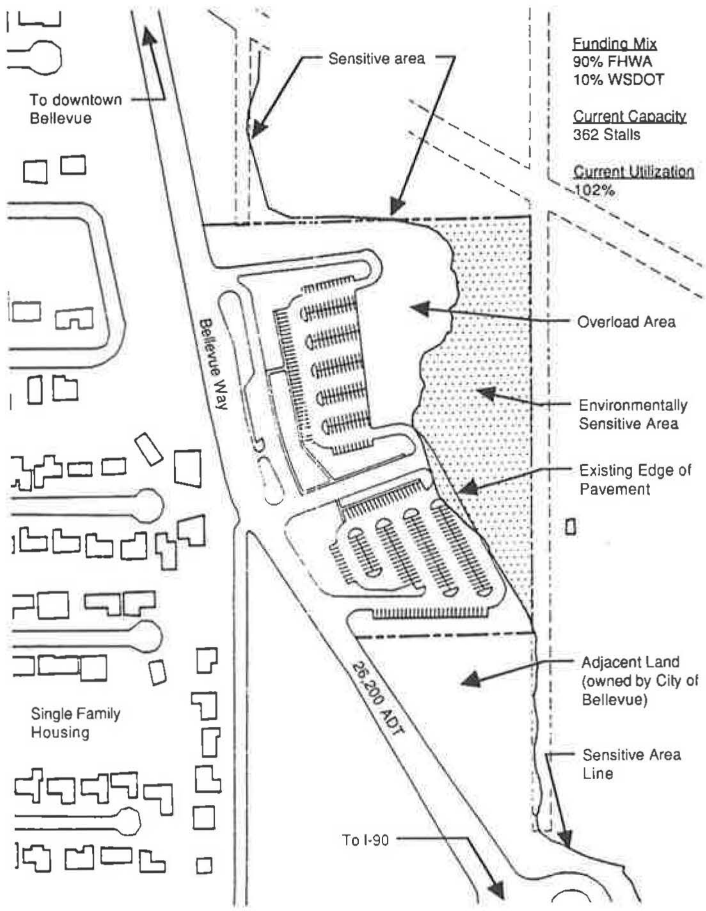

FIGURE 5 Site analysis and land use study, South Bellevue park-and-ride lot.

park development planned by the city of Bellevue, utilization is more than 100 percent, need for more parking exists on the site, and adjacent land use suggests that day care is the most suitable development.

Day care is an excellent option for development adjacent to this site. The proposal for day care was based on the following factors:

- Additional parking capacity is needed at the facility.
- The city of Bellevue owns all of the land surrounding the site and intends to build an interpretive center adjacent to the southern border of the site. A day-care center could be incorporated into park buildings.
- "High-end," single-family housing has been developed across from the site.
- Market demographics indicate that day care would be viable in this location.
- Day care does not depend on arterial frontage, which is not an option at this location.
- Sufficient space on Bellevue's site exists to support the development of day care at this location.
- The development of a park by the city of Bellevue around the site with interpretive nature trails would make this location excellent for children.

The development of day care with the city of Bellevue would present several institutional issues and design challenges. They could be addressed by creating a shared-parking agreement between the operators of the interpretive center and the transit operator (Metro), providing a drop-off area for the day-care facility and five parking spaces for day-care workers and visiting parents, adhering to all applicable codes of the city of Bellevue, providing a 10,000-ft^2 play area for children and a 7,000-ft^2 pad for the day-care facility, maintaining a 50-ft setback from the established sensitive area line for all structures, and increasing the attractiveness of the park-and-ride facility by introducing additional professionally designed and installed plant materials.

WSDOT is interested in developing additional capacity at this site. An analysis of the as-built grading plans and several site visits indicate that approximately 113 additional parking spaces can be developed in a previously graded overflow area. If the interpretive center were constructed, approximately 50 additional spaces could be obtained through the development of a shared-parking agreement.

Figure 6 shows the proposed layout of a day-care center, farmers' market, and interpretive center. A key implementation issue is the development of additional park-and-ride spaces near a sensitive area. This issue may require additional mitigation for the existing and proposed parking.

I-5 and 164th Street (Proposed Park-and-Ride Facility)

Figure 7 shows the site and characteristics. Considerations for this future facility include the severe traffic congestion along

164th Street, the creation of sufficient space for a park-and-ride lot at this location by realignment of Ash Way, the development of channelization and access management for 164th Street, the designation of the interchange of 164th Street and I-5 as a possible interim terminus for a high-capacity transit line that is under study, and the potential for on-site retail at this site.

Convenience retail was selected as the most appropriate use at this site on the basis of the market and site analysis findings. Among the findings were that sufficient average daily trips are made along 164th Street to support retail, there is a lack of convenience services to the west of I-5 along 164th Street, the interchange of 164th Street and I-5 is a high-exposure corner, reconfiguration of the intersection of Ash Way and 164th Street is planned, and the opportunity exists to integrate on-site services in the planning phases of the facility.

The development of a jointly used facility depends on meeting the needs of both the transit and the retail functions. The design objectives were tailored to provide

- Sufficient parking for retail patrons,
- Landscape areas around the retail center to make the facility attractive,
- Pedestrian linkages across the site from north to south and from east to west,
- Covered pedestrian walkways wherever possible,
- Links to adjacent areas with sidewalks,
- A pedestrian waiting area near the convenience services,
- Designated crosswalks in any location where pedestrians would cross vehicular traffic,
- Convenience services that are quick to use,
- A freeway flier stop along the southbound off-ramp to 164th Street,
- A circulation system with minimal left-turn movements,
- Transit-only lanes to ease access for transit to and from I-5 and the site,
- Shelters in the retail building structure,
- Additional shelters at the freeway flier stop, and
- Maximum exposure for retail operations from both 164th Street and the park-and-ride facility.

The development of the site was to be divided into two phases to spread capital costs and judge actual demand.

The development for the proposed facility is shown in Figure 7. The site closely approximates the concept of retail integration that provided the impetus for the study.

CONCLUSION

Many benefits could be associated with joint development of park-and-rides. They include attracting new riders; providing

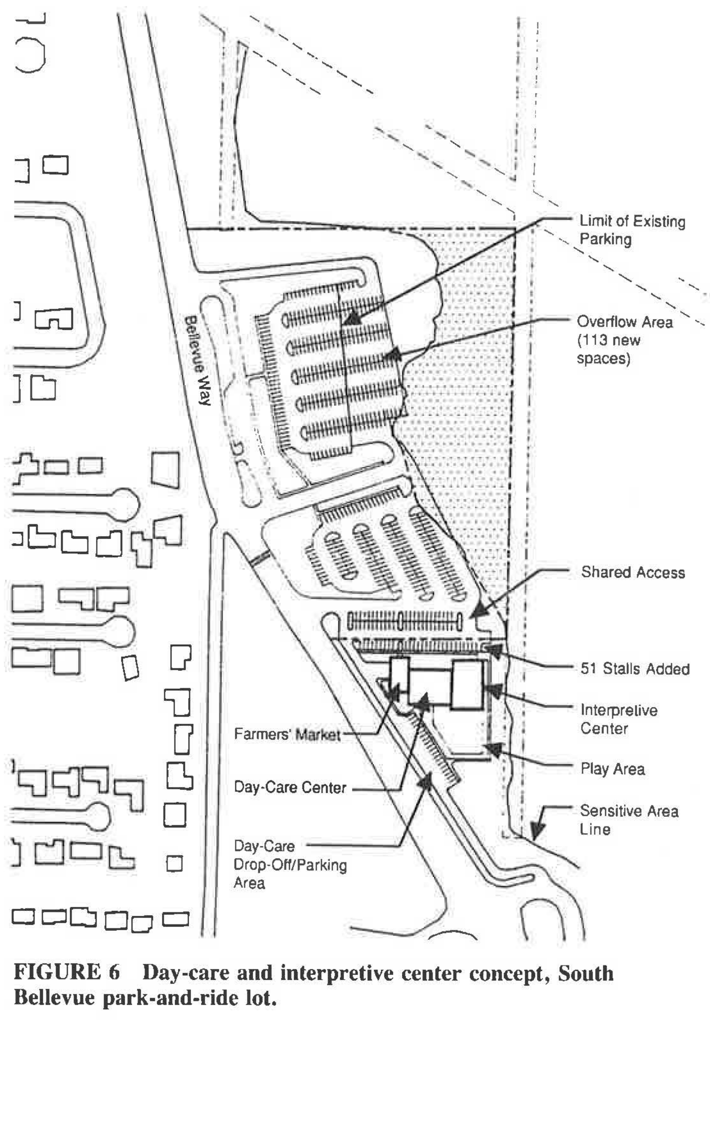

FIGURE 6 Day-care and interpretive center concept, South Bellevue park-and-ride lot.

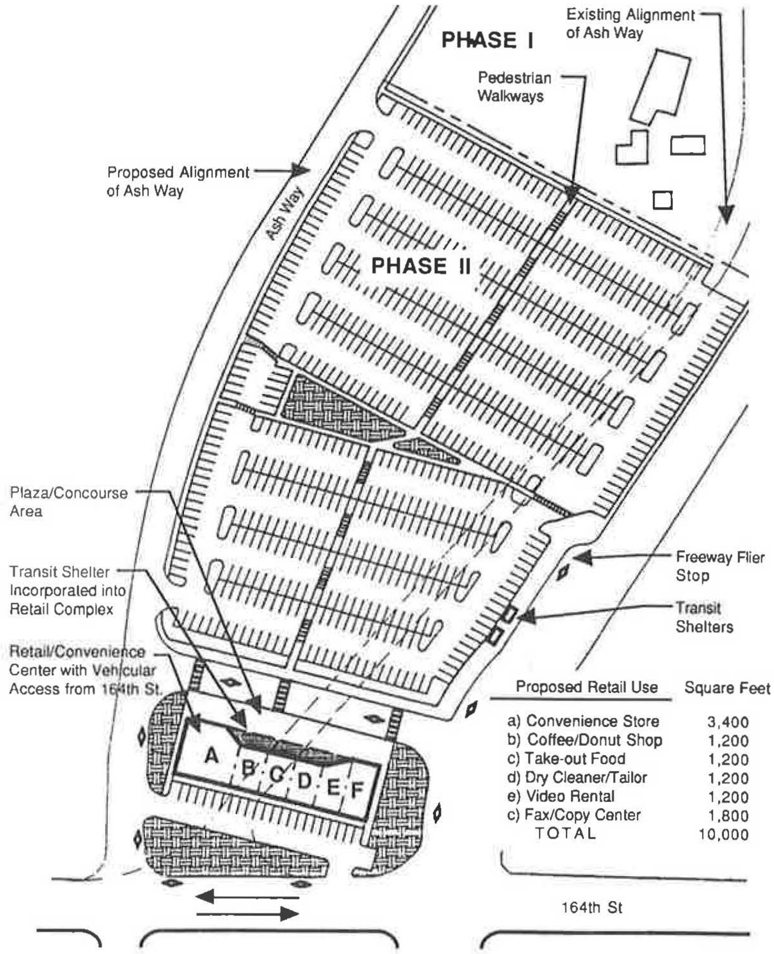

FIGURE 7 Park-and-ride development concept with retail: Snohomish County, 164th Street and I-5.

lot security; increasing rider satisfaction and reducing automobile trips through the provision of retail services; and obtaining additional park-and-ride spaces through joint use agreements, land trades, or with revenue generated by joint developments. The possible benefits need to be confirmed through implementation of these concepts and evaluation of results. There appears to be enough promise to try some demonstration sites.

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Short History of the Transbay Transit Terminal and the Relocation of the San Francisco Greyhound Depot Thereto

GREGORY C. MCCONNELL AND GEORGE E. GRAY

The Transbay Transit Terminal (TTT) in downtown San Francisco is the busiest terminal on the West Coast. Constructed in 1939 as part of the San Francisco–Oakland Bay Bridge railway, the TTT was converted for bus use in 1959. Currently, the Bay Area's four major public bus systems use the structure, as well as Amtrak (bus) and a number of private transit providers. In April 1990 Greyhound Lines moved its San Francisco depot into the TTT. The TTT is adjacent to San Francisco's central business district and at the physical and financial heart of the Bay Area. Many proposals for alternative uses have been made. It was once thought that the construction of the Bay Area Rapid Transit under the bay would render the TTT obsolete. However, the need for the structure and site as a regional transit terminal has been affirmed as transportation problems have become of foremost concern to the people of the region. After years of neglect the California Department of Transportation plans to completely renovate and refurbish the structure. Coupled with the relocation of the Greyhound depot and the planned development of the San Francisco CalTrain terminal adjacent to the TTT, this will allow the structure to become a truly regional transit terminal.

The Transbay Transit Terminal (TTT) in downtown San Francisco is one of the busiest transit facilities in the country. Each weekday more than 50,000 commuters use its stairs, escalators, or ramps. The facility turned 50 in 1989.

Conceived as the western terminus for the San Francisco–Oakland Bay Bridge rail service and constructed as part of the bridge, the TTT is located in San Francisco's central business district. It is within walking distance of two Bay Area Rapid Transit (BART) subway stations and is near access to three major automobile corridors—the bridge, the James Lick Freeway (Highway 101), and I-280 (see Figure 1).

The TTT was converted for bus operations in 1959 and is currently used by the following public operators: Golden Gate Transit (GGT), Alameda and Contra Costa County Transit (AC Transit), San Mateo County Transit District (SamTrans), and the San Francisco Municipal Railway (Muni). Amtrak provides a bus service from its train station in Oakland. Several private tour operators also operate from the TTT during off-peak commute hours.

As gridlock, pollution, and an overburdened, inadequate, jurisdictionally balkanized, and financially divergent mass transit system has increasingly become of concern to the people of the San Francisco Bay Area, the TTT may finally receive the recognition and attention it deserves. Greyhound Lines has recently moved its San Francisco operations into the TTT, and an adjacent site has been proposed as one of the final alternatives for the downtown depot of the west bay commuter rail service, the Peninsula Commute Service (CalTrain). The California Department of Transportation (Caltrans) is committed to renovating the structure as a modern, safe, and efficient multimodal transportation facility.

A brief history of the TTT and the relocation of the Greyhound depot thereto is presented.

District 04, Public Transportation Branch, California State Department of Transportation, P.O. Box 7310, San Francisco, Calif. 94120.

TERMINAL CONSTRUCTION 1937–1939

In 1929 the state legislature created the California Toll Bridge Authority (CTBA) to finance, construct, and operate the San Francisco–Oakland Bay Bridge. Financing for the bridge and the terminal was primarily provided by the federal Reconstruction Finance Corporation (*1*). Originally, the state planned to run a rail service between San Francisco and Emeryville, where it would connect with the Key System and Southern Pacific (SP) electric trains. This plan was abandoned when the Key System and SP offered to terminate their ferry service and run their electric trains over the bridge (*2*).

Consequently, in 1935, CTBA negotiated agreements with the Key System and the Interurban Electric (the SP subsidiary) to provide the first rail connection between San Francisco and the East Bay via the San Francisco–Oakland Bay Bridge (see Figure 2). The "Bridge Railway" included, among other facilities, "the San Francisco Terminal and viaduct and all tracks and appurtenances, between the terminal and connections with the existing lines in Alameda County" (*3*). "On September 4, 1935, the Authority adopted the Plan 'X' terminal located between Beale and Second Streets" (*4*) (Figure 3).

Demolition and Design

The project necessitated the demolition and removal of buildings on 34 parcels of land, including parcels required for viaduct construction. Total demolition costs were $133,944.36, and demolition was completed on August 9, 1937 (Figure 4) (*6*).

CTBA instructed the architects Timothy Pflueger, Arthur Brown, Jr., and J. J. Donovan that the design of the terminal "be governed by the controlling principles of convenience to the passenger and an architectural treatment that was suitable to a public building in a metropolis" (*3,7*). This led to a

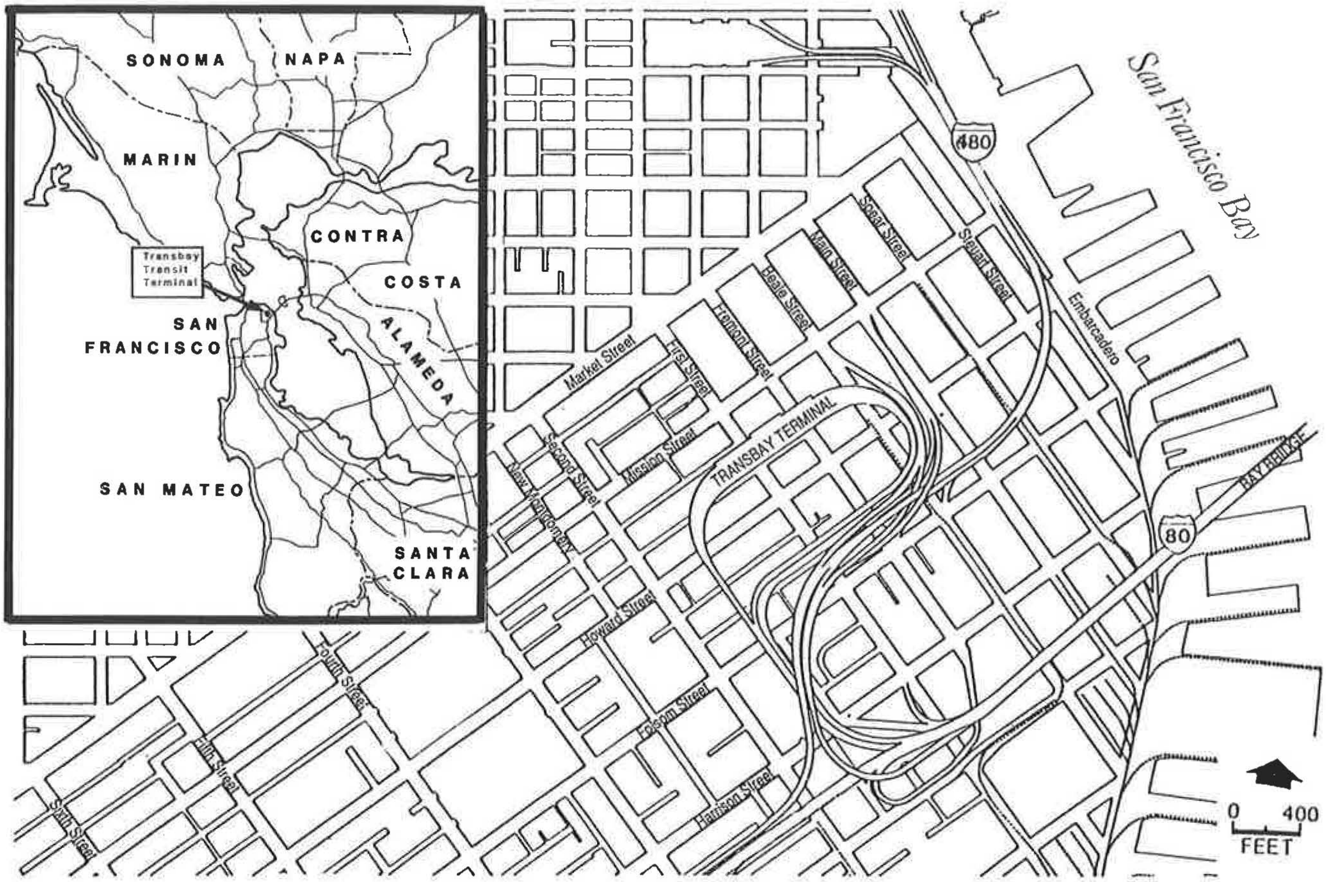

FIGURE 1 Location map.

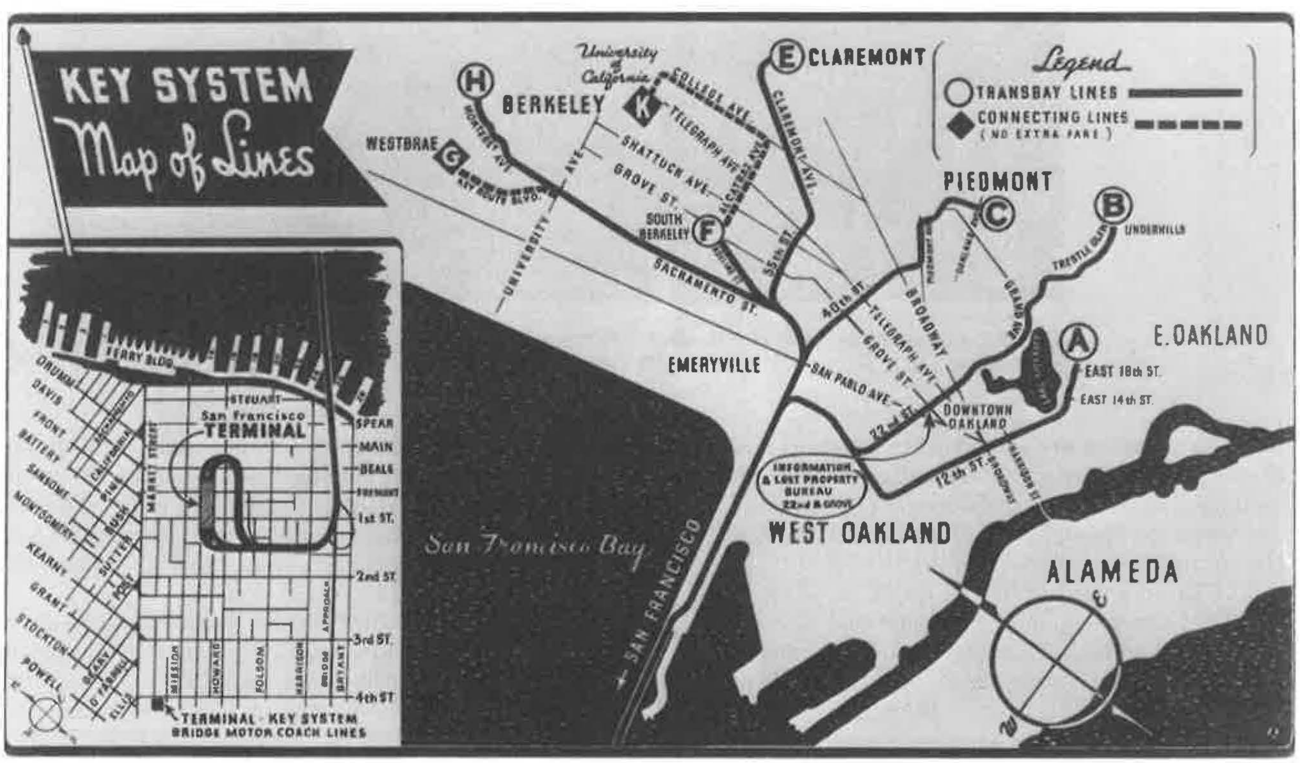

FIGURE 2 Key System (from 1940 Key System schedule, courtesy H. W. Demoro, *San Francisco Chronicle*).

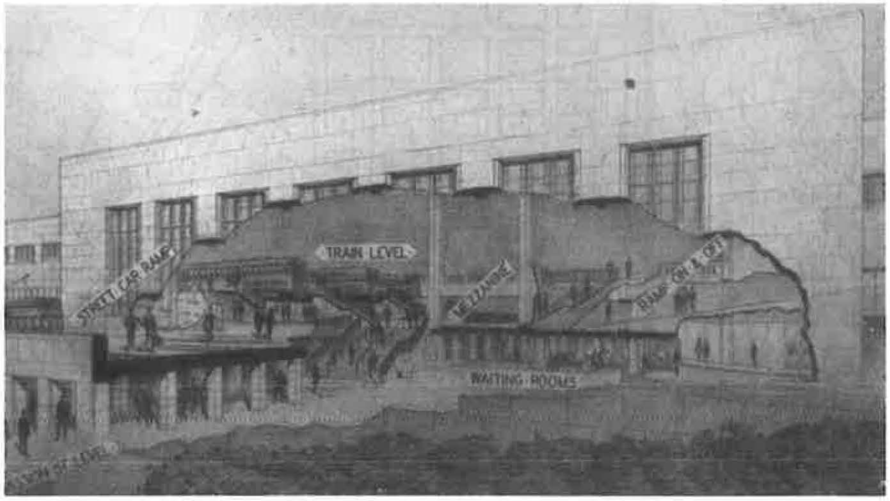

FIGURE 3 Architect's drawing of the terminal (*5*).

FIGURE 4 Demolition of 34 city blocks for terminal and viaduct construction (*3*).

structure with a "system of enclosed ramps and stairs providing the shortest path from any of the adjacent streets to the various trains" rather than a conventional railroad terminal (*3*). The ramp, or "hump," was designed to bring Muni's streetcars to the front mezzanine level.

The TTT was designed to have a length of 870 ft. It is trifurcated by Fremont and First streets into east, center, and west units. The third floor track level extends over the entire structure. All units have a basement, first, mezzanine, and track floor. The first floor is at street grade. This level in the center unit was designed as the waiting room with rest rooms and concessions. Store space was provided on the street floors of the east and west units. The mezzanine floors were to be used as transverse concourses allowing access to all tracks. The east and west units are 164 ft wide, and the center unit is 197 ft wide. Six tracks were constructed to allow trains a 5-min loading and unloading period. Fences between the pairs of tracks prevented passengers from straying on the tracks (Figure 5).

Whereas the Sacramento Northern (under contract with the Key System) and the Key and SP systems were electrically operated and used standard-gage tracks, the latter two used different technology and voltage systems. This complicated the design of the San Francisco–Oakland Bay Bridge and the TTT. Rather than convert all to a common system or put changeover equipment on the Key cars, an overhead 1,200-

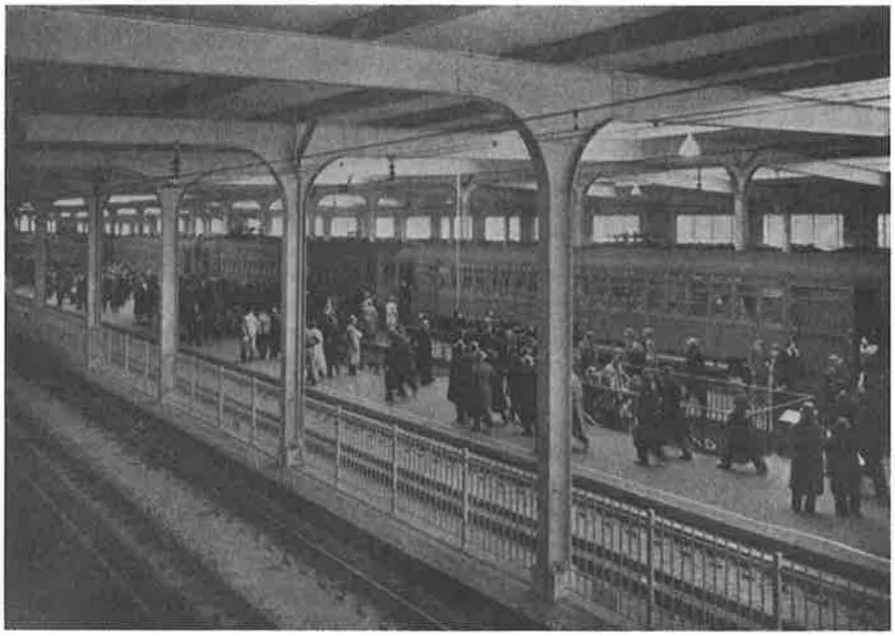

FIGURE 5 Track level of terminal, 1939 (*8*).

V wire was provided for the SP and Sacramento Northern Trains, and the Key trains used a 600-V third rail on the bridge and the TTT and 600-V overhead wire on city streets (*9*). East- and westbound trains shared a viaduct between the bridge and Clementina Street, where the viaduct separated to form a gigantic loop that encompassed the equivalent of seven city blocks (Figure 6).

Garage space for more than 600 cars was provided in the basement, street, and mezzanine floors of the west unit and in the basement of the center unit. Cavernous basement storage space was used during the 1950s and 1960s as a civil defense depository containing emergency food and medical supplies. Greyhound Bus Lines was one of the first tenants, leasing a travel agency and telegraph office. Other original

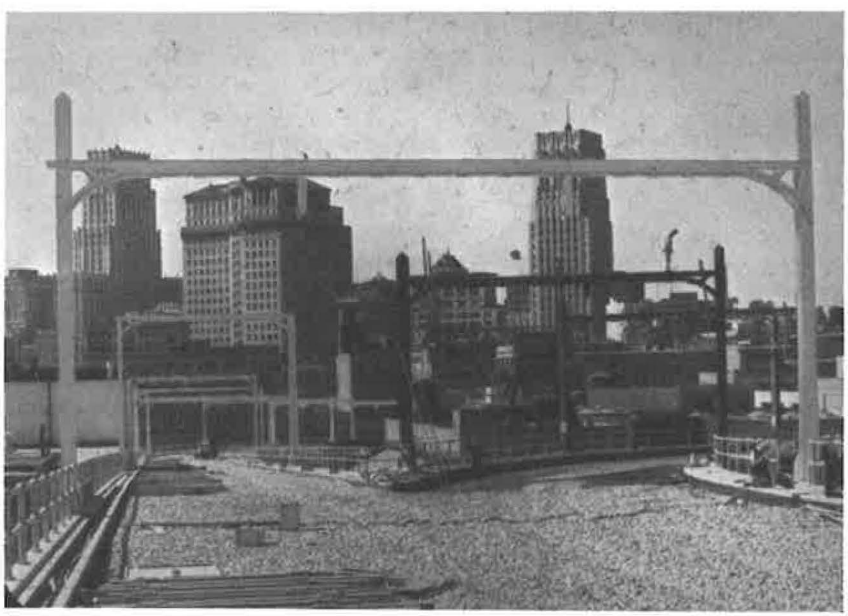

FIGURE 6 Terminal viaduct under construction. Note gravel track ballast and overhead trolley wire support frame. Trains proceeded counterclockwise at the gore. Source: Caltrans.

concessions included a soda fountain and lunch counter, newsstands, flower stands, fruit and candy stands, a drugstore, and a bootblack (*8*).

Construction

Approximately 4,000,000 lb of structural steel was used for the rigid steel frames supporting the tracks over First and Fremont streets, 560,000 lb for the catenary bridges, and 2,800,000 lb of steel roof framing (*10*). Flat-slab concrete completed the shell. The Mission Street facade consists of 4-in. granite slabs from the Sierra Nevada. Interior design called for plastered ceilings, tile walls, and terrazzo floors in the ground floor lobby beneath the streetcar ramp, the waiting room, and the mezzanine concourse of the center unit. East and west unit concourses, the headhouse floor, and all ramps have concrete floor surfaces. During 1937 four major contracts were let for terminal construction: general construction, structural steel, mechanical work, and electrical work. The total construction cost, including minor contracts, was $3,053,818.43 (*6,10*).

The contracts for the Bridge Railway were close enough to completion to permit the start of operations on Sunday, January 15, 1939. The facilities were officially transferred to the use of the interurban companies at ceremonies held in front of the TTT at noon on January 14. Two Key System seven-unit trains carried the official party of 1,500 persons across the bridge from Oakland into the TTT. The ceremonies occurred on the streetcar ramp or "hump." The TTT was opened for public inspection after the formalities (Figure 7).

The TTT was originally named the Bay Bridge Transit Terminal, the name affixed to the facade in 1946. It was renamed the Transbay Transit Terminal in 1958.

TERMINAL RECONSTRUCTION 1958–1959

Automobile and bus competition, coupled with reduced bridge tolls, forced the Interurban Electric and the Sacramento Northern to abandon their lines over the bridge just 2 years after initiation. In addition, the Key System was purchased in 1946 by National City Lines, a front corporation for General Motors, Phillips Petroleum, Mack Truck, Firestone Tire, and Standard Oil. As it did to other trolley systems across the country, National City Lines converted portions of the Key System's passenger transportation to motor coaches, often paralleling service provided by the transbay electric trains. The city of Oakland contributed to the death of the Key System in the mid-1950s by converting downtown streets to a one-way system, incompatible with the two-way trolley (*11*). Naturally, train patronage suffered, declining from a maximum of 37,334,000 in 1945 to 6,113,000 in 1957. In 1955 the Key System petitioned the California Public Utilities Commission for permission to abandon its rail service and inaugurate motor coach service. The commission complied, and the last train crossed the bridge on April 20, 1958 (*12*). In 1956 Alameda and Contra Costa counties organized the AC Transit District, which was to assume responsibilities for the Key System routes.

In 1957 legislation was passed both approving studies on how to convert the lower deck of the San Francisco–Oakland Bay Bridge and the TTT, with approaches thereto, for exclusive use of vehicular traffic and providing $35,000,000 in reconstruction funds over a 4-year period. (Reconstruction costs eventually reached $55 million and were repaid with toll revenues.) Redevelopment of the system for transbay commuter traffic consisted of removing the tracks, paving the vacated areas, and remodeling the TTT for the accommodation of bus service. Included in the remodeling was con-

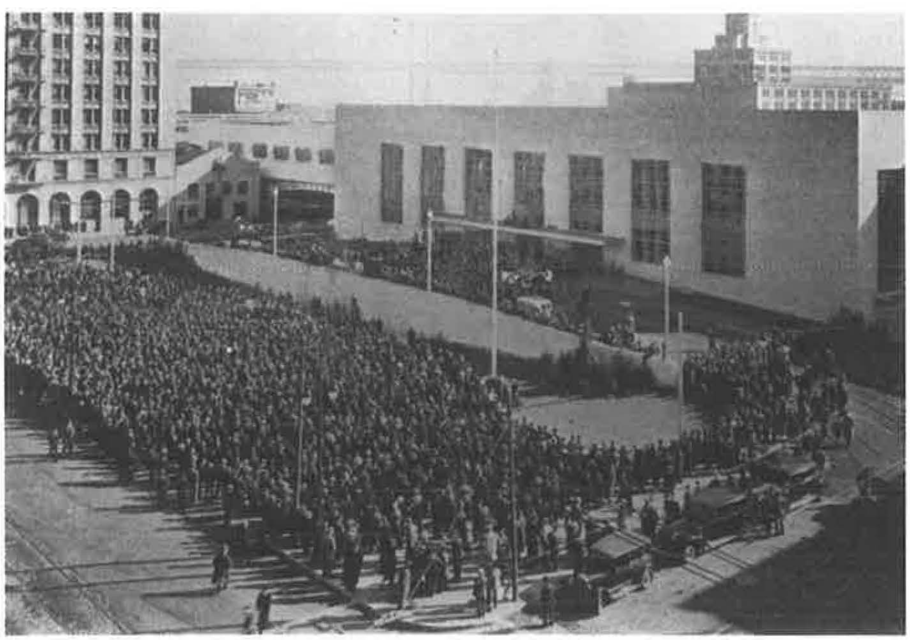

FIGURE 7 Opening ceremonies, January 14, 1939 (*8*).

struction of a new stairway to the garage area below the street level, installation of fluorescent lights in the main waiting room and on the mezzanine floor, the opening of various previously closed areas for freer movement of pedestrian traffic throughout the building, construction of a new ticket office, and installation of a new stairway flanked on both sides by escalators connecting the lobby to the mezzanine level (*13*).

Considerable planning and coordination were required for the changeover from trains to buses to alleviate the added traffic congestion resulting from the additional buses traversing the streets of San Francisco. Nevertheless, reconstruction started shortly after the cessation of rail service, and 14 bus lines were in operation by July 12, 1958. On February 1, 1960, Greyhound Lines began daily operation of 25 buses between the TTT and the east bay. The bridge opened for unidirectional traffic on October 12, 1963, nearly 5 years after reconstruction on the TTT and the San Francisco approaches began.

As noted, six tracks ran through the terminal in pairs, separated by columns supporting the roof (Figure 8). The tracks were removed, the columns were placed on the offside platforms, and the area paved, providing a roadway width of 25 ft, which allowed room for a moving bus to pass another at the curb. Coach stops were spaced two bus lengths apart, 10 in each roadway, a total of 30 for the three roadways.

STUDIES, PLANS, AND PROPOSALS

Whereas essentially only maintenance work was done between 1960 and 1989, there was no dearth of studies and proposals. Indeed, detailed plans for various Transbay terminals were proposed as early as 1930 (*15*). In 1959 a proposal was put forth for the construction of a Division of Highways (the precursor to Caltrans) office over the terminal providing two stories of office space and a heliport on the roof. Phoenix-like, the heliport concept ascended a number of times until it was finally grounded by the Federal Aviation Administration in 1966. In that year San Francisco's public utility manager proposed the abandonment of the downtown airline bus terminal and the establishment of "a downtown branch of the San Francisco Airport" for a future downtown transportation center at the TTT with "horizonal elevators" to Market Street (*16*). In 1967 a feasibility study was conducted in conjunction with the World Trade Center Authority for the construction of a World Trade Center. In 1969 a proposal was made by Greyhound to operate the facility.

In the early 1960s transportation engineers and conventional transit wisdom had it that the opening of BART service under the bay in 1974 would render transbay bus service and the terminal obsolete. However, a 1972 study commissioned by CTBA examined several alternatives and recommended replacement of the existing terminal with a new terminal built as part of a 2,000,000-ft^2 mixed-use office complex. The new terminal was to accommodate both continued bus commuter use and long-haul bus service (*17*). Costs were to be largely borne by developers through the purchase or leasing of air rights over the new terminal for high rises. Though public reaction to this proposal was generally favorable and developers showed interest, none could be found to finance the proposal. In 1972 the authority commissioned another study to complete a development plan by late 1974. However, late in 1973 this study was canceled as the passage by the state legislature of AB 3694, creating the San Francisco Bay Area Transportation Terminal Authority (SFBATTA), became imminent. SFBATTA became effective January 1, 1975. Its purpose was to "develop a regional transit terminal in the City and County of San Francisco on or immediately adjacent to the site of the existing transbay terminal."

The authority was composed of representatives of AC Transit, Caltrans, San Francisco, BART, MTC, GGT, SamTrans, and

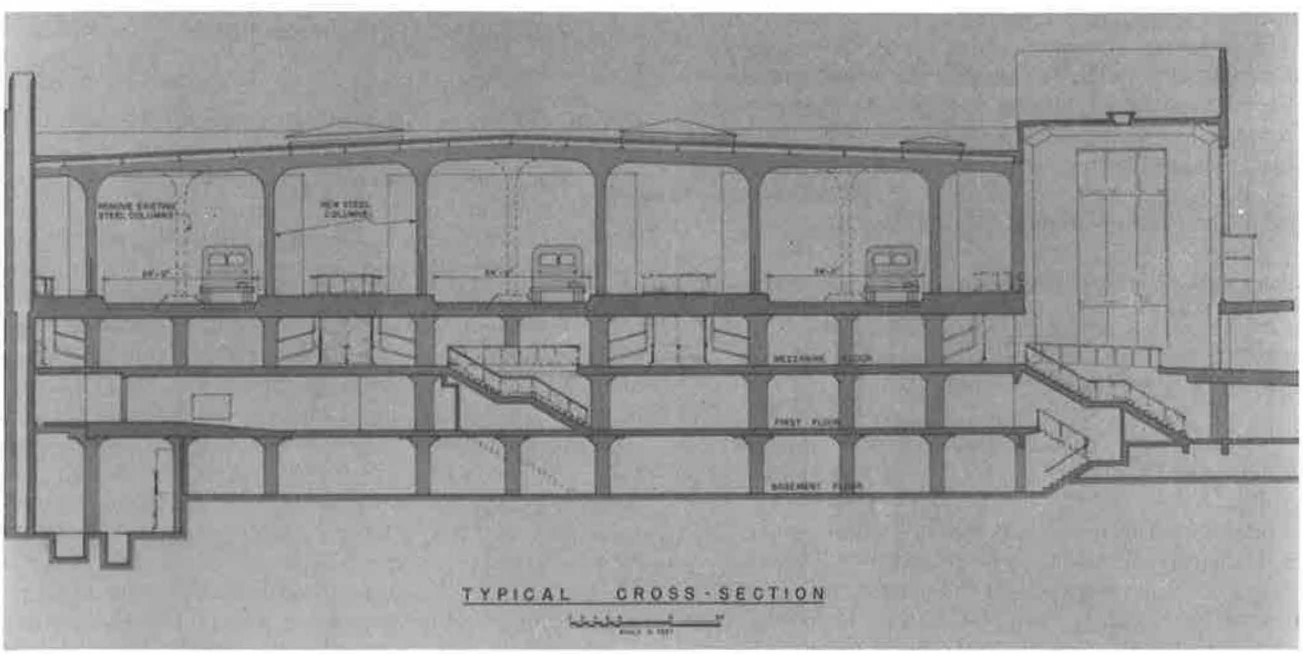

FIGURE 8 Remodeling of track level (*14*).

private transportation interests. SFBATTA commissioned a number of studies and issue papers. Several proposals were brought forward, including demolishing the structure; building over it; turning it into a parking structure, office complex, or urban plaza; expanding it with additional bus decks; providing west- or southbound connecting ramps to Highway 101; excavating underground people movers to the Montgomery BART Station; constructing an elevated pedestrian bridge over Mission Street; creating a joint bus-train station; and selling or leasing the structure.

In 1979 a draft environmental impact review, *San Francisco Bay Area Transportation Terminal Expansion*, was issued. It proposed a $50 million plan that included renovation, a second bus loading deck, lowering the "hump," building a pedestrian bridge across Mission Street, and other features. At that time, Greyhound Corporation representatives informed SFBATTA that they were dissatisfied with the terminal proposals, citing costs, delays, and a recent Greyhound survey of its own passengers indicating a preference for its existing Seventh Street site (*18*).

In 1981 SFBATTA issued its final report for improvements to the TTT (*19*). The "preferred alternative" included

> expansion onto an adjacent site in addition to expansion of the terminal building. . . . acquisition of . . . properties southeast of the existing terminal. These properties to be developed to accommodate package express facilities at the street level and long-haul bus loading zones at the two upper levels.
>
> The terminal would be rehabilitated by adding a second bus deck and new roof. The total floor space . . . would be increased from 400,000 to 780,000 square feet. . . . The terminal structure would be reinforced to meet current seismic safety codes.

This proposal drew a mixed reaction from major commuter bus operators and long-haul bus companies. Among the commuter bus operators, SamTrans elected not to join AC Transit and GGT in concentrating San Francisco operations at the terminal. Greyhound made it clear that it would not join Continental Trailways in making the terminal its primary depot. The Airporter, a private bus line connecting downtown to the airport, also declined to base its operations at the site. Consequently, SFBATTA chose to pursue a modified plan of renovation and expansion. Before approving the final proposal and effectively voting themselves out of business, John Mauro, the SamTrans representative on SFBATTA, expressed the frustrations of many (*20*):

> I don't know what these various agencies are contributing besides confusion. . . . The money has dried up and private developers have lost interest. I keep asking myself why I come to these meetings, except to decide where the money will come from for more consultants.

In accordance with state legislation (SB 702), SFBATTA was dissolved on December 31, 1981, and Caltrans took over the project.

Caltrans elected to implement the SFBATTA project in stages. Design commenced for a Stage 1 SFBATTA project. However, the design work was halted pending the outcome of proposals to relocate the San Francisco CalTrain terminal to a site immediately south of the TTT and to offer an air rights lease for joint development of office buildings over the bus-rail terminal complex. While these issues were debated, the need for renovating the TTT persisted.

A Transbay Transit Terminal Improvement Project was included on a list of projects to be constructed from federal funds originally set aside for completion of I-280 to the San Francisco–Oakland Bay Bridge. This $7 million project was never accomplished. In 1988 the citizens of the Bay Area passed Regional Measure 1, which increased tolls on certain state-owned bridges. Because of this and because the TTT is a part of the San Francisco–Oakland Bay Bridge facility, it was determined that the I-280 transfer funds originally set aside for the TTT would be better used elsewhere. Thus, it was proposed that the Terminal Improvement Project be funded by tolls, allowing the state total financial and jurisdictional control of the project.

In 1989 Caltrans conducted a study and produced schematic designs for major revitalization of the TTT. As a result of this study, a Transbay Transit Terminal Revitalization Project was proposed. The proposal comprised a $54 million project to modernize the interior; provide access facilities for the elderly and handicapped; improve security; implement current building code requirements; and provide mechanical, utility, transit, and tenant improvements. In 1990 the project turned into the presently proposed Transbay Transit Terminal Renovation Project, which has three categories: Category 1, to upgrade the facility to meet current building and safety codes and improve security; Category 2, to improve operational facilities for carriers; and Category 3, to rehabilitate rental space for the provision of modern terminal amenities for transit patrons. The total cost of this project has been estimated to be $54,078,000: $29,975,000 for Category 1, $22,080,000 for Category 2, and $2,023,000 for Category 3. Categories 1 and 3 will be funded through the department toll bridge Measure 1 funds. It is proposed that Category 2 be funded through Metropolitan Transportation Commission Measure 1 funds. Designs for Categories 1 and 3 are scheduled to be completed in 1992, and construction is scheduled to begin in 1993. In addition, Caltrans is investigating the feasibility of a child care facility in the TTT.

RELOCATION OF THE GREYHOUND DEPOT

Greyhound Lines, in its various corporate incarnations, has been involved in a symbiotic relationship with the TTT since its construction. As noted, Greyhound Bus Lines was an original lessee. At that time its buses stopped outside the terminal. In addition, from 1960 until the late 1970s Greyhound operated a commute service to the east bay. The service originated at its Seventh Street depot (see Figure 9) and stopped at the TTT before proceeding over the bridge. In 1969 Greyhound proposed to Caltrans that Greyhound lease the terminal for $200,000 per year. The proposal was for a 30-year lease with two additional 10-year options. Greyhound proposed to occupy two of the three lanes. According to optimistic ridership projections, a fourth bus deck lane would have to be constructed over Natoma Alley behind the terminal to accommodate AC Transit. It was determined that the Greyhound offer would not provide optimum return to the state.

As noted, in 1979, shortly after the completion of the draft environmental impact review *San Francisco Bay Area Trans-*

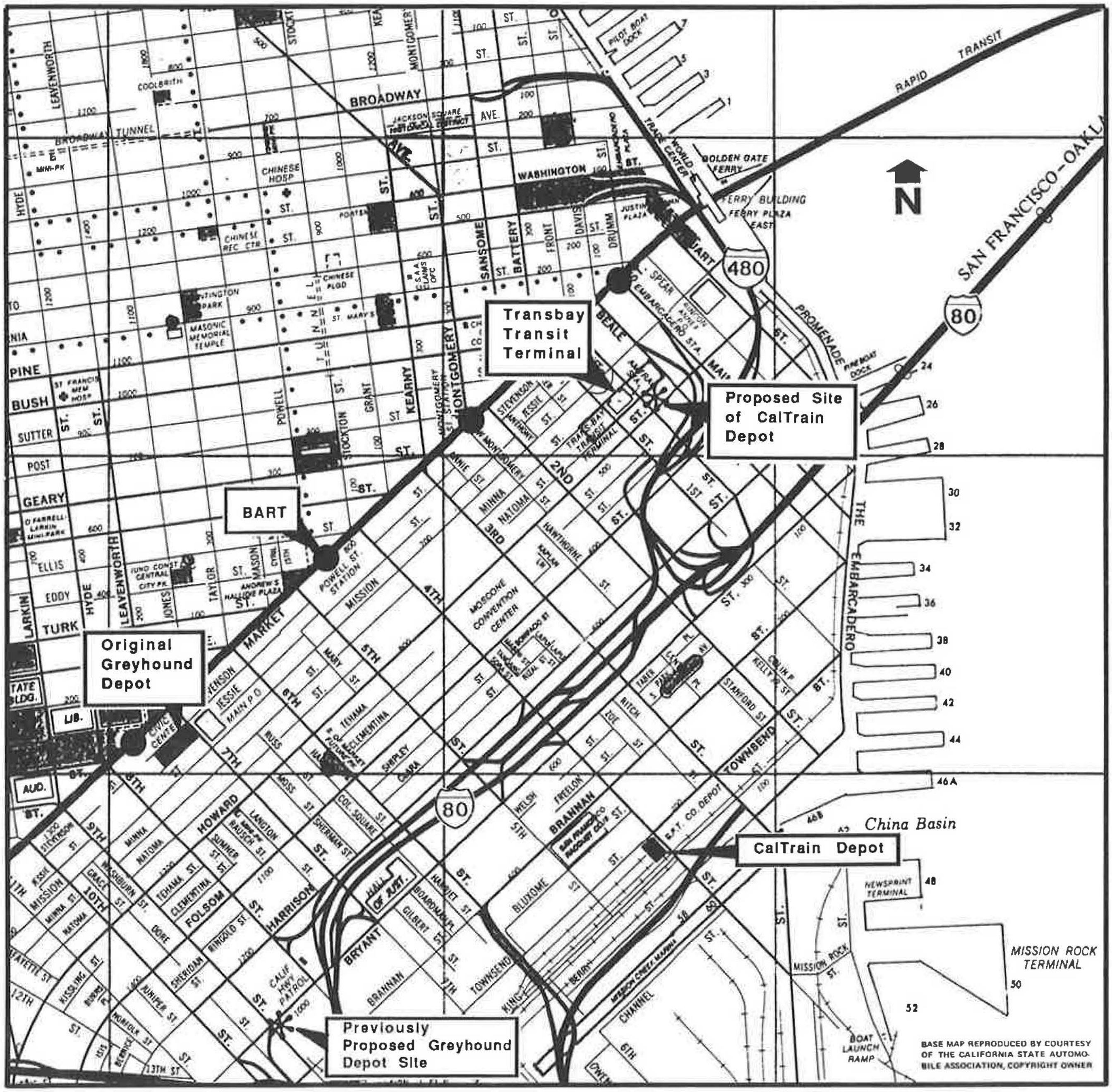

FIGURE 9 Existing and proposed terminals and stations in downtown San Francisco.

portation Terminal Expansion, Greyhound Corporation representatives informed SFBATTA that they were dissatisfied with the terminal proposals. Greyhound's withdrawal ended SFBATTA's grandiose plans, because without Greyhound's participation SFBATTA could not justify expansion of the terminal.

Greyhound continued to seek an alternative to its antiquated and increasingly inadequate facility at Seventh and Mission streets (Figure 9). The Seventh Street depot was constructed in the early 1940s primarily for the movement of troops during World War II. Greyhound officials acknowledged that the barnlike open-air loading shed and the tacky waiting room were, at best, substandard. In 1982 Greyhound executives proposed building a new three-story depot at Bryant and Ninth streets near Showplace Square, an upscale, swank designer enclave. However, Greyhound abandoned the proposal under pressure from local business people, who were concerned about the impact of the depot on their neighborhood, and city officials, who continued to campaign for Greyhound to relocate to the TTT (*21*).

In March 1987, Greyhound Corporation sold Greyhound Lines, the bus operation. The Seventh Street terminal was not included in the sale. In December 1987 Greyhound Corporation sold the terminal site to a local developer, who granted Greyhound Lines a 1-year extension on its lease. Whereas this was later extended, Greyhound Lines was faced with the necessity of finding a new site for its downtown San Francisco depot (22).

Reversing their earlier position, Greyhound officials approached Caltrans on December 23, 1987, about moving their San Francisco bus operations to the TTT. Caltrans, whose policy since the demise of SFBATTA has been to encourage the use of the TTT by Greyhound and other public and private operators, responded enthusiastically to Greyhound's proposal. Caltrans expedited construction because it believed that both the public and Greyhound would benefit. The public would have a depot closer to downtown with improved local and regional transit connections, and Greyhound would have a direct connection to the San Francisco–Oakland Bay Bridge and I-80 as well as a more modern, secure facility. To meet the short time frame brought about by Greyhound's losing its lease, Caltrans agreed to alter its often cumbersome project development process and use a design produced by a Greyhound architect. Caltrans secured appropriate historical and environmental clearances and oversaw actual construction.

Project Description

Greyhound's architect, Scott Windham, developed the preliminary design and overall concept for the project. IDG Architects of Oakland prepared the plans, specifications, and cost estimate. These were revised by Caltrans to meet state standards. Balliet Brothers of South San Francisco was the general contractor. The project included the following:

1. An additional floor anchored to the existing columns in the headhouse area of the TTT center unit was to be built. The new floor, with an area of 7,715 ft^2, matches the grade of the existing bus deck platform, and on it was built Greyhound's passenger ticketing area, rest room and waiting area, and baggage-handling room. Above this level was constructed a 2,340-ft^2 mezzanine office and driver waiting area. An elevator, two escalators, and a stairwell were also constructed to provide access to the new Greyhound passenger service level.
2. Lane 1 of the TTT bus deck was modified to provide "sawtooth" berths for 13 buses. The entire Lane 1 platform received a new architectural surface treatment (Figure 10).
3. A package express facility (11,750 ft^2) was constructed inside the street level area of the east unit. Two side-by-side elevators were constructed to provide rapid parcel transfer capability from the package express facility to the bus deck level. Behind the existing east unit a parking lot was constructed to serve the package express facility.

Construction began on May 25, 1989. Greyhound moved into the facility on April 26, 1990. The original completion date for the project was December 4, 1989. Completion was delayed mainly because of the unique nature of the structure and site. The removal of asbestos before construction caused a delay of 2½ months. Problems encountered during installation of the new east unit elevator caused another major delay. The 19th century shoreline of San Francisco Bay runs directly under the main terminal unit. The east unit is built on bay fill. When drilling under the east unit to provide space for the elevator machinery, an ancient piling from gold rush days was struck. The low ceiling in the basement prohibited the use of large drilling machinery. After 2 weeks of drilling with small augurs, little progress was achieved. It was then

FIGURE 10 Lane 1 and outside of new Greyhound depot in the TTT. Source: Caltrans.

decided to change the elevator to a "telescope" type, which did not require as much space. The new elevator machinery had to be ordered from Germany and took 45 days to deliver.

The new Greyhound facility is in stark contrast to the rest of the TTT. The new depot is brightly lit, clean, and plush with new tile, electronic information signs, and brilliant chandeliers. Leaping gracefully above the patrons, a large renovated 1930s neon sign of the Greyhound dog has been installed. This art deco, canine glass logo is now the only remaining such sign in the country (Figure 11).

Financing

Most of the funding for the project came from the state's toll bridge funds. Improvements solely for Greyhound's use were paid for by Greyhound. The total cost of the project was approximately $3,000,000. Greyhound's share came to approximately $680,000. Greyhound was granted a 20-year lease with options to extend the term for two successive 5-year periods. It is charged monthly rent on the basis of floor space and loading spaces used.

CONCLUSION—FUTURE OF THE TERMINAL

For years the TTT has been plagued by neglect and bad press. It generally came into the public eye only when there was a grandiose development proposal or complaints arose about its condition. Even when Caltrans repainted the interior in 1979, the public scorned the color selection. Allan Temko, Pulitzer Prize-winning architecture critic of the *San Francisco Chronicle,* expressed the public outrage (*23*):

> [The bus deck] is an important space. With its graceful steel framing . . . and the glass surfaces . . . pouring light . . . [it] had a particularly happy welcoming mood: airy, clear, refined.
>
> The mood is gone. Instead of elegance and lucidity, there is turgid, vulgar incoherence: a wild array of ill-assorted colors battling with one another. They are no good individually, and absolutely terrible together. . . . The mess is made worse by the ugliest brown I've seen in a spell: not earthen, or truly warm, but a congealed outhouse paste spread over the steel. . . .
>
> These random, unrelated hues were not taken from a torn-up sample book, but were deliberately picked. In a mad bit of bureaucratic heraldry, Caltrans combined all the colors of the different transportation systems that use the terminal.

FIGURE 11 Neon greyhound, last of its kind. Source: Caltrans.

The TTT has since been repainted. In 1983, when new transit information displays were erected, the *San Francisco Examiner* announced that "a shiny new Transit Information Center has opened in the shabby innards of the Transbay Terminal . . ." (*24*).

However, favorable impressions were made on a jubilant public when on November 16, 1989, 1 month after the October 17, 1989, Loma Prieta earthquake destroyed a section of the San Francisco–Oakland Bay Bridge, the TTT served as the loading point for the "bridgewalk" and reopening ceremony. Approximately two-thirds of the 13,000 participants queued outside the TTT to be shuttled to Yerba Buena Island, where they trekked to the rebuilt section of the bridge. There the governor and other dignitaries spoke, reminiscent of the Bridge Railway ceremonies only 51 years ago.

Whereas the TTT generally receives media attention during cyclic spasms of boosterism and grandiose development proposals or as a staging ground for ceremonies, its real function is performed every day, by providing a safe and efficient system for the loading and unloading of thousands of passengers.

Through neglect, earthquakes, public scorn, and indifference, the TTT has stood as a silent sentinel, stoically performing its function. Rejuvenated by the addition of the Greyhound facility and awaiting planned improvements, it stands ready to serve yet another half century as the busiest bus terminal west of the Mississippi.

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Airport Development with Automated People Mover Systems

WILLIAM J. SPROULE

The ability of many airports to handle future air passenger demands is constrained by the capacity of terminals or ground access facilities. Various transportation systems to reduce walking distances and provide for efficient movement of passengers in the airport should be studied. Though the impetus for the development of automated people mover (APM) systems was the desire to develop less labor-intensive solutions to urban transit problems, one of the major applications has been at airports. Unique development opportunities have evolved. APM systems currently operating at airports and the characteristics of five airport projects under development are described, and lessons in the application of APMs are identified.

Air passenger traffic continues to grow at dramatic rates. The growth has put added pressure on airport facilities, and congestion and delays have become unacceptable at many airports. As a result, plans are being developed and implemented to cope with this growth. The plans range from major modernization and expansion projects aimed at increasing capacity at existing airports to the construction of new airports.

The objective in the planning of air passenger terminals is to achieve an acceptable balance between passenger convenience, operating efficiency, facility investment, and aesthetics. One measure of convenience is walking distance. Most authorities agree that 600 to 700 ft (180 to 220 m) is a reasonable design criterion for passenger walking distances in a terminal and that anything longer than 1,000 ft (300 m) is unacceptable (*1*). However, as terminal buildings are expanded, walking distances increase. At some airports, it may not be possible to expand an individual terminal because of site constraints, and an additional terminal or satellite must be constructed elsewhere on the site. As a result, the consideration of various transportation systems to reduce walking distances and provide for the efficient movement of passengers in the airport has become more common.

There appear to be three broad classifications of these systems:

1. Driver-controlled systems, which are operated by a driver (e.g., buses, vans, mobile lounges, and tow trains or carts);
2. Continuous systems, which are nonintermittent and are under the control of a switch (e.g., moving walkways and escalators); and
3. Automated systems, which are under the control of an automated device [e.g., automated people mover (APM) systems].

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Each system has characteristics that make it appropriate for its application. Because no single system can satisfy all the transportation requirements encountered at various airports, each airport must determine which system is best suited to its needs. Several different systems can often be seen at one airport. The application of APM systems at airports is examined in this paper.

APMs

An APM is an advanced transportation system in which automated, driverless vehicles operate on fixed guideways along an exclusive right-of-way. These systems are also known as automated guideway transit, people movers, and by various other names.

APMs come in a variety of designs. They can be rubber tired, steel wheeled, suspended, or drawn by cables. Depending on the supplier, there are differences in guiding, switching, and control concepts. However, they have a number of characteristics in common.

First, they are smaller, lighter, and more maneuverable than light rail or heavy rail transit vehicles. Vehicle capacities can range from 4 to 6 passengers in small vehicles to more than 150 passengers in larger vehicles. Vehicles can be linked to form trains. Second, because of the typical short ride duration and frequent stops on most systems, the vehicles are usually designed to carry a large standing load of passengers with few seats. Third, the vehicles are designed for fully automated operation with no driver or attendant on board. Aside from potential savings associated with driverless operations, opportunities for short headways and service capabilities to better meet demands are possible.

Although the impetus for the development of APMs was provided by the desire to develop less labor-intensive solutions to urban transit problems, one of the major applications has been at airports. The features that have made them attractive for consideration at airports include operational flexibility, reliability, cost-effectiveness, environmental aspects, safety, and image.

AIRPORT SYSTEMS

Today, there are 11 airports with APM systems. Eight are in the United States, two are in the United Kingdom, and one is in Singapore. The systems can be categorized into two groups: (*a*) intraterminal, for the movement of passengers in a terminal or between the central area and a satellite building;

and (*b*) airport circulation, for the movement of passengers on the airport site between terminals, parking lots, and regional rapid transit stations.

Although there are several variations of these basic groups, the most common systems operate in a shuttle configuration within a terminal. The characteristics of operating airport systems are summarized in Table 1.

The first application of an APM system was at Tampa International Airport. In a review of major airport terminals at the time, it was found that walking distances tended to increase with the growth of air passengers, because lengthening of piers was the common means of expanding capacity. In virtually all cases the walking distances were greater than generally accepted maximum guidelines, and walking distances were especially long for passengers who had to transfer between airlines. A separation of landside functions from airside functions was advanced as an effective solution for airport terminal design to reduce walking distances. This would also group related passenger and aircraft processing more efficiently. The solution became known as the "satellite" concept. However, it was realized that the success of any such concept would depend on a means of transferring air passengers efficiently and comfortably between airside and landside. The revolutionary terminal opened in 1971 with a central landside terminal and four airside facilities, all connected by APM vehicles that shuttle on elevated guideways between the components. Similar shuttle configurations have been incorporated in the design of terminal facilities in Miami, Orlando, Las Vegas, and Gatwick airports. Present expansions at the Tampa and Orlando airports have incorporated shuttles to new airside buildings. Construction in Tampa to link a parking lot with the terminal building by using an APM system has recently started.

At Seattle-Tacoma Airport, planners were faced with the need to expand the terminal but were constrained by the site, so a people mover system was used to link the existing terminal building with two new satellite buildings. The system consists of a shuttle in the main terminal building and two one-way loops located in tunnels under the apron.

Other airports have more elaborate networks. At Houston Intercontinental Airport, a people mover is located in a tunnel and connects four terminals, a hotel, and parking areas. At Atlanta Hartsfield Airport a variation of the landside-airside concept was developed to accommodate the large number of transferring passengers. An APM operates in a tunnel located under the apron and links the main landside terminal with four concourses or airside buildings. Passengers can also walk or use moving walkways in the tunnel between buildings.

The most extensive system opened in 1974 at Dallas–Fort Worth International Airport. On a network of overlapping routes, vehicles transport passengers and airport employees between four terminals, a hotel, two remote parking areas, and a maintenance facility. The system, known as Airtrans, has about 13 mi (20.9 km) of single-lane guideway and 32 stations. Studies are under way to change the system to accommodate possible expansion and changes in American Airlines operations at the airport.

People mover shuttles have been developed to link air terminals at Gatwick and Birmingham airports with British Rail train stations.

PLANNED AIRPORT SYSTEMS

Several airports have APM systems in various stages of development, and many airports have included people movers

TABLE 1 CURRENT AIRPORT APMs

Airport	Description	Start of Service	Configuration	Length of Guideway	Number of Stations	System Supplier
Tampa International	Shuttles connect landside terminal to 4 airside buildings. Shuttle added to new airside building in 1987.	1971	4 shuttles	1.4 miles (2.2 km)	8	AEG Westinghouse
		1987	shuttle	0.5 miles (0.8 km)	2	AEG Westinghouse
Houston Intercontinental	Closed loop connects 3 air terminals, hotel, and remote parking area. System extended in 1990 for new terminal	1972	closed loop in tunnel	1.5 miles (2.3 km)	9	WEDway - replaced an original system by Rohr, 1981: WEDway system now available from TGI-Bombardier
		1990		0.2 miles (0.3 miles)	2	
Seattle-Tacoma International	Two loops connected by shuttle service. Each loop operates in one direction and links central terminal with a satellite in a tunnel under apron.	1973	2 loops in tunnel and shuttle leg	1.7 miles (2.7 km)	8	AEG Westinghouse
Dallas-Fort Worth International	Network for passengers and employees connects 4 terminal buildings, hotel, and remote parking areas. Called "Airtrans".	1974	network of overlapping routes	13 miles (20.9 km)	32	Vought Corporation
Atlanta Hartsfield International	System links 2 landside terminals with 4 remote airside buildings. Operates in Transportation Mall tunnel under apron.	1980	pinched loop with turnbacks in tunnel	2.4 miles (3.8 km)	10	AEG Westinghouse
Miami International	Shuttle between landside terminal and airside building. Cars on train reserved for passengers who have not completed U.S. Customs entry procedures.	1980	shuttle	0.5 miles (0.8 km)	2	AEG Westinghouse
Orlando International	Shuttles connect landside terminal to 2 airside buildings. Shuttle added to new airside building in 1989.	1981	2 shuttles	1.5 miles (2.4 km)	4	AEG Westinghouse
		1989	shuttle	0.7 miles (1.1 km)	2	AEG Westinghouse
Gatwick, London, U.K.	Shuttle between landside terminal and airside building.	1983	shuttle	0.4 miles (0.6 km)	2	AEG Westinghouse
	Second system shuttle to link new North terminal to South terminal and British Rail train station.	1988	shuttle	1.5 miles (2.4 km)	2	AEG Westinghouse
Birmingham, U.K.	Shuttle between new terminal and British Rail train station. Maglev vehicles.	1984	shuttle	0.4 miles (0.6 km)	2	People Mover Group - a consortium of British Rail, British Government, and engineering companies.
Las Vegas McCarran International	Shuttle between landside terminal and airside building.	1985	shuttle	0.5 miles (0.8 km)	2	AEG Westinghouse
Singapore Changi International	Shuttles link landside and airside stations in two terminals.	1989	2 shuttles	0.8 miles (1.3 km)	3	AEG Westinghouse

in their long-range master plans (*2,3*). The characteristics of five projects in the United States are summarized in Table 2 to show some unique applications.

Chicago

O'Hare Airport is currently undergoing a major program of modernization and expansion. An APM system is included in the program. The system is being built by Matra, a French company, and will connect a remote parking lot, rental car facilities, a future international terminal, and the existing domestic terminals. Initially there will be three stations in the terminal area. A fourth station, serving the international terminal, will be added when that terminal is complete. From the terminal area, the guideway will proceed north to a long-term parking lot. A station serving rental car facilities has been proposed, and the O'Hare master plan envisions future extension of the system to serve additional remote parking lots and airport-related activity centers, such as hotels and office complexes. The system is now under construction, and it is expected that service will begin in 1991.

Pittsburgh

At Greater Pittsburgh International Airport, design is under way on a midfield terminal complex to accommodate projected passenger traffic growth. An APM system will shuttle passengers between a landside terminal and an airside building in a tunnel that will also include a pedestrian walkway. Construction is under way, and the system is scheduled to open in 1992.

Denver

Planning is under way for a new airport to replace Stapleton International. The proposed terminal concept is similar to Atlanta Hartsfield, in which an underground people mover system links a landside terminal with airside buildings. The system will operate as a "pinched loop" with trains traveling from the landside terminal to airside buildings on one guideway. At the last airside station, trains switch to the adjacent guideway and return to the landside building. The first phase of the system will serve three airside buildings. The system is scheduled to be operational in 1993–1994, when the new airport opens.

New York (Kennedy International Airport)

One of the most ambitious systems currently under design is at Kennedy International Airport in New York City. The Port Authority of New York and New Jersey has recently embarked on a major program to modernize and expand Kennedy.

The major bottleneck at Kennedy is the terminal roadway or ring road, which serves the unit terminals. To reduce congestion, the Port Authority plans to build a new transportation center building in the center of the terminal area. New access roads will be built to serve the transportation center, and this building will be linked to five unit terminals with APM systems. Provisions are being made to link to other unit terminals and other airport activity areas.

To relieve traffic congestion on the ring road, all public transit vehicles will be required to use the transportation center. Here passengers will be able to buy tickets, check and claim baggage, and enjoy the typical airport terminal amenities. From the transportation center, passengers will be shuttled to their terminal on a people mover system. Passengers connecting between terminals will simply ride a shuttle to the transportation center and then transfer to another shuttle and ride to their connecting terminal.

Completion of the project was anticipated for the mid-1990s, but the start of construction has been delayed and terminal redevelopment plans are under review.

Newark

The Port Authority of New York and New Jersey has also started a major improvement program for the ground access

TABLE 2 SELECTED AIRPORT APMs UNDER DEVELOPMENT

Airport	Description	Start of Service	Configuration	Length of Guideway	Number of Stations	System Supplier
Chicago O'Hare International	System links remote parking with domestic terminal. Plans to add stations at rental car facility and new international terminal.	1991	pinched loop with turnbacks	2.6 miles (4.3 km)	4	Matra
Pittsburgh International	Shuttles connect landside terminal to airside building.	1992	shuttle in tunnel	0.9 miles (1.5 km)	2	AEG Westinghouse
New Denver International	System links landside terminal with 3 remote airside buildings.	1993-1994	pinched loop with turnbacks in tunnel	2.3 miles (3.9 km)	8	AEG Westinghouse
New York Kennedy International	Shuttles connect new Transportation Center to 5 unit terminals.	mid-1990's	5 shuttles on elevated guideways		10	AEG Westinghouse
Newark International	System links 3 terminals with 2 long term parking lots.	1994	pinched loop with turnbacks	1.8 miles (2.9 km)	5	Vol Roll Transport

facilities at Newark International Airport. In addition to major roadway realignments and an increase in parking capacity, an APM system will be built. Initially the system will have five stations that will link three passenger terminals with parking lots. Future expansion will include a station at which passengers can transfer to a proposed regional rail system.

The unique aspect of this APM system is that it will use a building envelope and guideway supporting structures that were incorporated in the original terminal design developed more than 20 years ago. Vol Roll Transportation has been awarded contracts to provide the superstructure, vehicles, and controls. Construction is expected to be completed in 1994.

APPLICATIONS

APM systems have been used in various airport applications. As mentioned earlier, the applications can be grouped into two categories, intraterminal and airport circulation. Intraterminal service systems are typically important components of new terminals and are "must ride" systems (that is, no other choice is available). Airport circulation systems have been used to link passenger terminals with each other and with parking areas, hotels, regional rapid transit stations, and other activity centers on site. The increased use of APMs, together with the variety of possible applications, has led to an assortment of network configurations (*4*). Examples of the basic categories and network configurations are shown in Figure 1.

APM systems have unique performance capabilities and characteristics. A planner has a wide latitude in configuring a system to match the needs at an airport. The potential to extend service off site and link hotels, offices, remote parking lots, rental car facilities, and other major activity centers with the airport has been identified. The potential is unlimited.

Comparisons of APMs with other possible modes are usually site specific. Selection of a transportation system is largely a matter of local decision and is based on local requirements and desired standards of service for the airport (*5*). Studies generally follow a conventional systems approach, developing measures of effectiveness, generating alternative courses of action, modeling performance, carrying out a multicriteria evaluation of alternatives, and then selecting the preferred alternative.

EXPERIENCE

Since the first APM system was incorporated in the passenger terminal at Tampa International Airport almost 20 years ago, several lessons have been learned. This experience has been documented in several reports (*6–8*), and some of the most important lessons are summarized as follows.

1. Consider the application of an APM system early in the planning process to ensure good design integration.
2. Recognize that the most successful systems have been the simplest.
3. Plan as much flexibility into the system as possible to respond to changing conditions at an airport.
4. Involve system suppliers early in the planning process.
5. Select the technology and the system supplier at the earliest possible date so that the specific requirements of the selected system can be incorporated to achieve design and construction cost efficiencies.
6. Recognize that system reliability is important. A system failure could severely disrupt airport operations.
7. Consider the degree of commitment of the system supplier. Many firms have abandoned the APM market, and this has caused some difficulties in obtaining replacement parts.
8. Exercise caution when a supplier proposes that an installation be used as a "test bed" to prove a new system. New systems must be tested, but the risks and benefits must be carefully weighed.
9. Plan the system so that it is easy to use. Design clear information and instructions on how to use the system.
10. Hire and retain good operations and maintenance personnel.

	Current Systems											Selected Systems Under Development				
Categories	Tampa	Houston	Seattle-Tacoma	Dallas-Fort Worth	Atlanta	Miami	Orlando	Gatwick, London	Birmingham U.K.	Las Vegas	Singapore	Chicago O'Hare	Pittsburgh	New Denver	N.Y. Kennedy	Newark International
INTRA-TERMINAL																
Shuttle Alignment	●		●			●	●	●		●	●		●			
Loop Alignment			●													
Transportation Mall					●									●		
AIRPORT CIRCULATION																
Terminal - Terminal		●		●								●				●
Terminal - Parking Lots		●		●								●				●
Terminal - Transit Station								●	●							
Terminal - Other Services on Site		●		●								●				
Transportation Center															●	

FIGURE 1 Applications of airport APMs.

CONCLUSIONS

APM systems have proved themselves in various airport applications. The range of performance capabilities and network configurations of this advanced transportation mode provides the airport planner with exciting opportunities. APM systems have become important components in the development of new airside-landside passenger terminal concepts. The transportation mall and the transportation center are two examples of new applications of these systems. The success of APMs has also led to the examination of various airport circulation systems to link passenger terminals with each other and with parking areas, hotels, regional rapid transit stations, and other activity centers both in and adjacent to the airport. Imaginative uses of APM systems are being considered.

Although the selection of transportation systems for moving people in an airport is largely a local decision based on local requirements and desired standards of service, it is expected that interest in APMs will grow. The ability of many airports to handle future air passenger demands is constrained by the capacity of terminals or ground access facilities. Airports are searching for better ways to move people.

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The Maturing Airport People Mover Field—Four Rounds of Experience at Tampa International

LAWRENCE L. SMITH

In the late 1950s the first pedestrian conveyor device was installed in Love Field in Dallas, Texas. Airport planners wanted to eliminate the long walk. A decade passed and a small people mover system was installed at Houston Intercontinental Airport in 1969. The system connected the unit terminals and eventually the airport hotel in a small underground loop and was an attractive passenger convenience. In 1971 Tampa International Airport incorporated four people mover shuttles as a "must ride" feature of the landside-airside hub-and-spoke layout. The instant success was quickly translated into a series of similar installations, all provided by Westinghouse—the only vendor with a proved technology at that time. In the mid-1980s a fifth shuttle was added. Currently a smaller, non-Westinghouse system to link a new parking garage is being built, and a sixth shuttle is planned. Facts and impressions on the basis of experience with four rounds of procuring and operating people movers are presented.

The "must ride" concept implies that the airport user must ride the people mover conveyance because there is no other means of access between stations, except during emergencies. The shuttle cars travel the station-to-station distance much faster than any passengers can walk or run.

The title "must ride" may convey a negative meaning. However, it had more to do with the fact that we did not intend or desire to build covered corridors paralleling the trackways. We have eliminated the costs associated with building that structure and the continuing operating and maintenance cost of air-conditioning, lighting, heating, cleaning, and maintaining a superfluous corridor. The space alongside the people mover guideway is accessible and usable as an emergency walkway only during rare emergency conditions. During occasional stoppages of cars in the trackway, passengers are given an audible message to remain in the car because maintenance is on the way. The maintenance technician usually reaches the car and drives it into the station in a few minutes without undue passenger distress.

As the decade of the 1990s begins, 10 automated airport people movers exist—7 from the dominant supplier and 3 from others. Eight new systems are under construction—at Singapore, Orlando (new leg), Tampa (new loop), Chicago, Pittsburgh, Tokyo-Narita, Frankfurt, and Newark. Work is about to begin at Osaka-Kansai and Denver. Serious planning continues at New York's JFK and LaGuardia. The airport people mover is no longer a novelty and will be as common as loading bridges, baggage carousels, escalators, and magnetometers in the large airports built or expanded after 2000.

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In the early days of people mover experimentation and trials, government agencies and trade associations conducted studies of feasibility, cost, reliability, energy, and accidents. Library references have proliferated faster than installations. Publications more than a few years old are obsolete or in need of major updating.

The airport people mover business is now a fledgling industry and boasts its own privately sponsored bimonthly trade journal (*Transit Pulse,* founded in 1983 in Boston, Massachusetts). There are other indicators of maturity—the recently formed Monorail Society listed the "I rode the ALWEG at the 1962 World's Fair" button selling for $8.00 in good-to-fair condition.

The maturing of this new industry brings with it conventional dilemmas and new problems. The crisp daring of the inventors, ground breakers, and risk takers and their collective can-do, must-do diligence have mellowed into today's routine business environment.

START-UP EXPERIENCE AND MATURATION

As owners and operators of one of the earliest airport systems, we too have learned a lot about our end of the business. The early traumas of troubleshooting, debugging, and fear of failure produced a winning effort that brought our system to a standard of reliability within the first year of operation that has persisted for the past 19 years.

Our original venture in this unproven but promising technology was not without the usual owner protection clauses in the procurement contract. We included penalties for downtime and precise means of notification and timekeeping. Damages were to be assessed at $10.00/hr for every hour over 12 accumulated in a month. Unless otherwise agreed, notification of an outage and back in service was to be by full-rate telegram. Hard-copy delivery of the telegram within 4 hr was guaranteed; the cost in 1971 was $5.00 for the first 15 words ($15.00 today).

We never sent or received a telegram, nor did we ever collect a $10.00 charge. The 12-hr grace period is equivalent to approximately 98.3 percent contract service availability. In 1976 we renegotiated the 5-year maintenance contract. By mutual consent we deleted the damage assessment clause for the 1971 cars and added specific language that availability must be maintained to the standards established during the first 5 years as shown in the statistical history of the day-by-day performance of the system.

Third and fourth 5-year maintenance contracts followed in 1981 and 1986. The old cars are now "senior citizens"—almost 20 years old—and are still operating, on the average, above 98 percent contract service availability. The old cars received 2-week interior renovations in 1985 at a cost of about $50,000 per car. We expect to get about 10 more years of service from the old cars. However, we believe that this will require some expensive renewals and replacements to completely rehabilitate essential electronic systems.

START-UP EXPERIENCE—THE SECOND TIME AROUND

The troubleshooting and debugging phase of the 1988 models to serve a fifth airside terminal was twice as long as that of the pioneer models. Although the supplier was the same company, its attitude was characterized by typical new car dealer arrogance at the warranty counter. The can-do spirit of the pioneer troubleshooter was replaced by the "why me" attitude of endless legal interpretations. Nonetheless, the newer system's performance improved.

Figures 1 and 2 show the steadily declining penalty assessments and the related steadily increasing contract service availability. In the first 6 months after inception of service, the system averaged $4,000 per month in penalties and 96 percent availability. In the next 6 months penalties dropped to an average of $2,900 per month, and availability climbed to 97 percent. Penalties for the next 6 months dropped to $2,300 per month, and availability increased to 98 percent.

The system performed for the first time without penalty and above the 99 percent availability benchmark during the 20th month. After 2 years of debugging, we now have a near "constant-state" condition, with availability hovering around 99 percent for 1990.

The penalty calculations and acceptance criteria for the new system are far more precise and definable in the contract, and that is a direct result of our experience as owners. The new cars are also an improvement over the old cars, and that is a direct result of the dealer's experience with its product line. The sophistication of the industry now includes standard practices for product modification, component testing, recall, and precise definitions of outages and verifiable accounting of downtime.

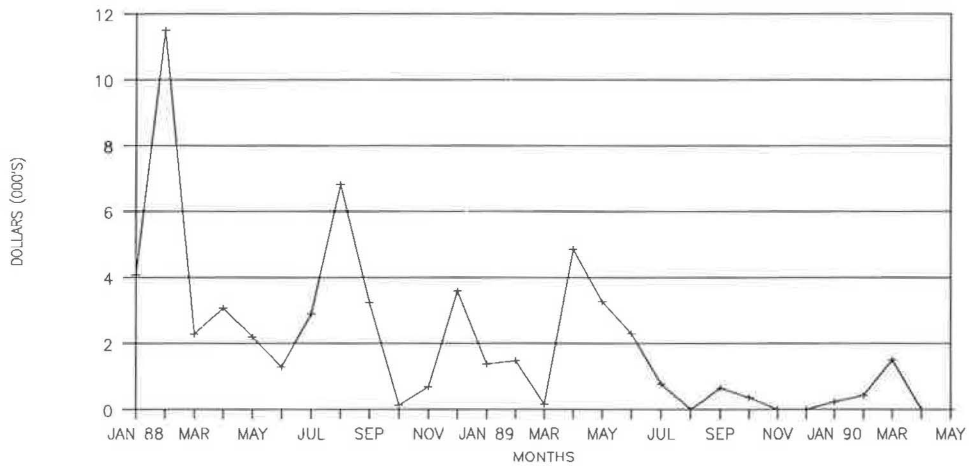

FIGURE 1 Tampa International Airport passenger transport system, Leg F—monthly penalties.

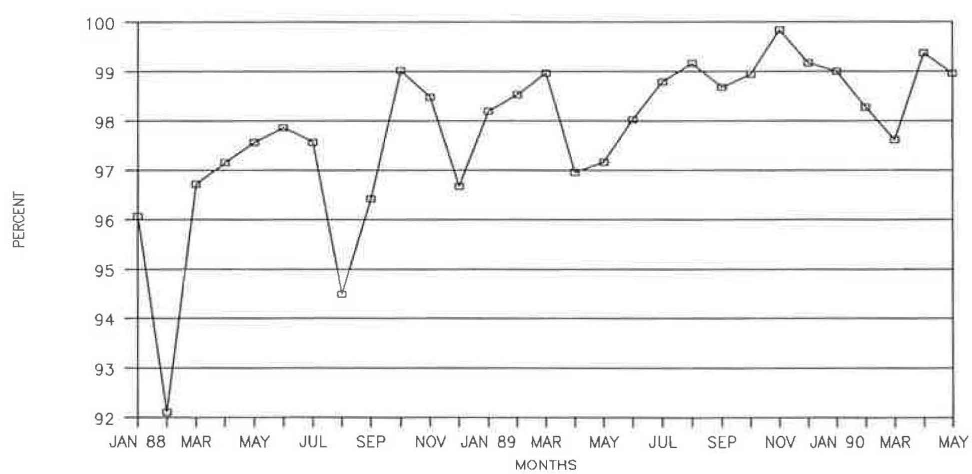

FIGURE 2 Tampa International Airport passenger transport system, Leg F—contract service availability.

The telegraph message has been replaced by facsimile machines and computerized data retrieval to the nearest minute, and the penalty rate has been changed to $5.00/min. The contract service start-up availability goal is 99 percent, and the exceptions and definitions of downtime have become more standard as owners share their wisdom and experiences.

CURRENT PROCUREMENT

The people mover marketplace today presents buyers with a selection of makes and models, end-of-year sales, and cars to fit their style and taste. Tampa International Airport has again stepped into the marketplace and recently procured a sporty, little compact people mover that will be just right for moving passengers from a massive new parking garage to our existing terminal building.

The new parking garage is enormous on a world scale. Each floor covers 11 acres and will accommodate 1,000 vehicles. The first phase of construction will produce five floors. The scale of the new facility presents the same problem as the 1970 challenge of minimizing passenger walking. Our original parking capacity was 2,600. When the new garage opens, we will have 8,800 parking spaces stacked on the same land area as the original layout.

We adopted the same passenger convenience philosophy and built the garage structure in its best location and maximized its utility and economies of scale. The walking distances, this time with luggage, would be horrific and similar to the endless hikes and dreaded shuttle buses at the typical sprawling airport parking facility.

The automated people mover was easily the most passenger-friendly device to circulate through one floor of the 11 acres of new structure and tie into the fifth floor of our existing terminal rooftop garage. Twelve elevators (spaced three per quadrant) will transport passengers to the shuttle lobbies.

The new system will have six minicars, each holding about 17 passengers and revolving in a 2,800-ft pinched loop configuration serving four stations in the new garage and three stations in the existing terminal building. With five cars in the loop, the system will manage a 70-sec headway and provide for a spare car in the maintenance facility. Tampa International Airport never had the luxury of a spare car on its airside people movers. This evolution is akin to the first spare tire strapped to the running board.

The new system was procured after 1½ years of evaluation of vendor products had narrowed the field to three serious vendors that offered models of airport people movers that fit this application. The contract was awarded to Transportation Group, Inc., for system installation, 5 years of maintenance, and an owner training option, for a total of $13.2 million. AEG/Westinghouse offered a system for $25.5 million, and Von Roll offered a system for $29.9 million.

We believe that this transportation device will be more successful than our original landside-airside people mover and more attractive to the public because they are carrying luggage. The earlier "must ride" system was not challenged with handling luggage, because luggage is checked in the main terminal building and transported by airline equipment to the airplane.

The south parking garage is scheduled to open in late 1991. We believe that this concept will be an early success. We expect that other planners will reconsider the intangible value of passenger convenience and repeat the concept in new applications for airport people movers. The market will further grow as planners see the value of linking other people collectors: airport hotels, garages, rental car facilities, limousine and taxi stands, and other pedestrian destinations.

Another wave of airport planners working on the latest all-new airport project has descended on Tampa to visit the cradle of airport people mover technology. A delegation from Hong Kong's Chek Lap Kok Airport is considering far greater people mover applications than we did 20 years ago. There is no longer a question of whether the system will work, but rather how can it be linked to the mass transit systems in the surrounding community. It appears possible that Chek Lap Kok will pass a new milestone—the airport people mover as boundary interface with the outside community.

DEALER SERVICE IN 1990 (THE FINE PRINT)

Maintenance of people movers continues to be primarily by outside contractors. However, we have not seen much progress in standardizing the pricing of these services. For example, the procurement contract, not including the 5 years of maintenance, for the garage system produced construction cost submissions for equipment from the three vendors of $10 million, $16 million, and $24 million. The companion bids for operations and maintenance costs were $2 million, $8 million, and $4 million, respectively. The variation from low to high is seriously distorted and leads one to wonder what is so mysterious about maintenance contract pricing. The three vendors all priced their maintenance against the same operations and maintenance staffing minimums and reliability criteria, and we cannot explain why the variability among the three vendors ranges from the low bid to the low bid raised to the third power.

The overwhelming caution is "don't buy without a 5-year/500,000-mi warranty" or some suitable equivalent for your application. Also beware of specialty components, such as switches, controls, and radio systems. You may want extended warranties on these items, especially on innovative concepts.

The best, most carefully written warranty can be voided with improper maintenance. Few owners have sufficient expertise to protect themselves from claims of maintenance neglect in the event of system component failure. Therefore, it behooves the new system owner to procure the system with full service and maintenance during the initial 3- to 5-year warranty period. The owner can specify that system training be conducted throughout the warranty period and in this way prepare for in-house maintenance. The pros and cons of contract versus in-house maintenance are unique to each site, as are many of the terms and conditions of an appropriate procurement, maintenance, and extended warranty contract.

In today's marketplace there are many experienced system suppliers with a decided advantage over the novice system buyer. The prudent first-time buyer should visit operators of similar systems and carefully select a specialized consultant. The consultant should have knowledge of recent dealings with the contending vendors and be prepared to assist throughout preliminary system planning, procurement, specifications, acceptance testing, and start-up of the maintenance warranty and operations phase.

PROPHECIES

What does the future hold for the people mover marketplace? I offer a handful of predictions.

- This fledgling industry will soon boast having its own Big Three.
- The market shares will gradually solidify.
- Procurement and maintenance contracts will evolve into boilerplate formats similar to the elevator and escalator types.
- The world's shortest moving walkway will be commissioned in the 1990s, and it will be less than 75 ft long.
- Radio frequency controls will give way to hard wire or other forms of induced signals on stable carriers.
- Traction motors and cables will fill a small niche overshadowed by the new technology.
- The new technology will burst on the scene, ushered in and groomed by a new breed of pioneers—but it is unclear who they will be and what language they will speak.

Publication of this paper sponsored by Committee on New Transportation Systems and Technology.

Review of Four Alternative Airport Terminal Passenger Mobility Systems

WILLIAM H. LEDER

United States air travel is expected to grow at high rates for at least the next decade. In 2001 there will be 807 million passengers annually, compared with 400 million in 1985. As airport terminal facilities continue to increase in size, airport planners, designers, and operators will place more reliance on passenger mobility technologies to provide an acceptable level of service to both transferring and origin-destination travelers. Four such technologies are reviewed: moving sidewalks, courtesy carts, buses, and automated people movers. Examples of installations at U.S. airports are discussed. Salient features, including advantages, disadvantages, and limitations, are identified. A set of generalized system performance criteria are presented for use as a checklist by airport planners and designers. Conclusions about the applicability of each technology are included.

The growth during the past decade in United States air transportation is expected to continue into the 21st century. In 1980, 316 million airline passengers used U.S. airports. The Federal Aviation Administration forecasts that by 2001, annual U.S. airline passengers will reach 807 million, an increase by a factor of 2.6 in 21 years. The growth trend is shown in Figure 1. Planners, designers, and operators of airports, as well as the airlines, face substantial challenges in facilitating such remarkable increases in activity.

A consequence of the massive growth in air travel is that the scale of modern airport terminals often exceeds human proportions. To achieve designs with acceptable passenger walking distances and aircraft-to-aircraft transfer times, more reliance is being placed on technology. General increases in air transport activity and the development of airline connecting hubs have made and will continue to make passenger mobility within and between terminals a more important part of terminal planning and design.

The following passenger mobility technologies are reviewed in this paper: moving sidewalks, courtesy carts, buses, and automated people movers (APMs). Each of these technologies is used today at airports in the United States and foreign countries.

Before examining the four mobility technologies in detail, the question of why airport terminals need to be built on such a grand scale will be discussed.

AIRLINE OPERATIONS

To start with, airplanes are, in themselves, large. To illustrate that point, wingspan and maximum length for the range of common commercial transport aircraft in use today are given in the following table:

Aircraft Type	*Capacity (passengers)*	*Wingspan (ft)*	*Fuselage Length (ft)*
B 737-200	120	93.0	100.2
B 747-400	500	211.0	231.9

Because of the large size of aircraft, apron frontage dimensions associated with terminal buildings must be substantial.

In addition to the size of aircraft, the total frontage requirement depends on the fleet mix (relative proportion of aircraft types) and number of aircraft that must be simultaneously accommodated. Thus, a lot of terminal frontage is required to park and service a large number of modern commercial transport aircraft at the same time.

Connecting Hubs

After federal deregulation of air carrier competition, airlines generally abandoned their traditional point-to-point route structures in favor of hub-and-spoke configurations. Hub airports, besides serving origin-destination travelers, are used as transfer nodes where as many as 60 to 70 percent of the passengers only make connections from one flight to another. Aircraft from spoke origins arrive, passengers are exchanged, and the aircraft then depart for spoke destinations. That process is referred to by the airlines as a connecting bank. As many as 8 to 10 connecting banks may occur each day at a large hub. These banks produce significant peaks in activity separated by periods when there are not many aircraft or passengers at the terminal.

For an airline hub to function efficiently, passengers arriving on any given flight must be able to transfer to every other flight in the connecting bank. Therefore, all aircraft in the connecting bank must be parked at the terminal simultaneously. That is the requirement that leads to the terminal sprawl associated with large hub operations.

The airlines are interested in completing the connecting process as quickly as possible to maximize the productivity of their aircraft fleets. They schedule as many connecting banks as possible during the time of day that passengers desire to travel. Table 1 gives minimum on-line connecting times for six large hub airports to illustrate that point. Minimum connecting times, which are published in the *Official Airline Guide*, are used by airlines and travel agents in constructing passenger itineraries. The minimums become facility maximums from the viewpoint of terminal planners and designers.

Lea+Elliott, 1009 West Randol Mill Road, Suite 210, Arlington, Tex. 76012.

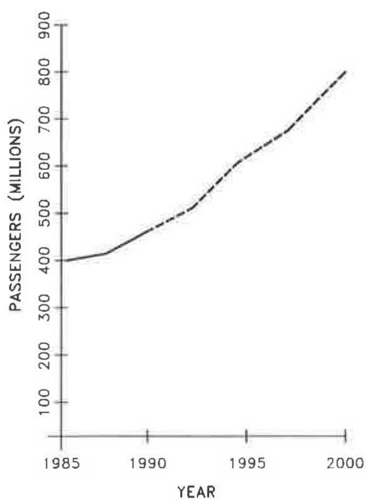

FIGURE 1 United States airline passenger growth.

TABLE 1 MINIMUM DOMESTIC ON-LINE CONNECTING TIMES (MINUTES)

AIRPORT	HUB AIRLINE	TIME
Dallas-Fort Worth	American	30
	Delta	30
Denver Stapleton	United	25
	Continental	25
Atlanta Hartsfield	Delta	35
	Eastern	30-35 (a)
Chicago O'Hare	United	29
	American	25-40 (b)
Detroit Metropolitan	Northwest	30
Charlotte Douglas	U.S. Air	30

(a) Depends on gate location

(b) 40 minutes if widebody aircraft is involved.

Source: Official Airline Guide, North American Edition, July 1, 1990, Vol. 16, No. 19.

Origin-Destination Passengers

Although much emphasis is currently placed on connecting passengers, there are large numbers of passengers who want to go to or from hub cities. They too must confront the great distances and times associated with hub terminals.

Other airports, without the high level of connecting passengers associated with the hubs, tend to be more origin-destination oriented. Many of them, because of general growth in air travel, have large-scale terminal facilities with long walking distances that consume substantial time. Some large airports that serve a high percentage of origin-destination travelers are Boston Logan, Las Vegas, New York La Guardia, Orlando, Seattle, Tampa, and Washington National.

Critical Reasons for Passenger Mobility Technology

The preceding discussion indicates that there are two critical reasons for the increased use of technology to aid passenger mobility within and between terminals. They are (*a*) continued vigorous growth in all categories of air travel for at least the next decade and (*b*) airline hubbing, which requires the transfer of large numbers of connecting passengers over long terminal distances in a short time.

ALTERNATIVE SYSTEM DESCRIPTIONS

Moving Sidewalks

The conventional moving sidewalk is a passenger-carrying device on which passengers may stand or walk. The passenger carry surface (treadway) moves at a constant, uninterrupted speed. Service is point-to-point along a straight line.

Nominal lengths vary from 100 to 400 ft. Local building codes often govern maximum lengths on the basis of emergency exit requirements. Treadway widths typically range from 39 to 55 in., with the 39-in. width predominating. Constant slopes up to 15 degrees (27 percent) are possible.

Moving sidewalk speeds are adjustable between 90 and 120 ft/min. A speed of 100 ft/min is typical. Suppliers do not recommend higher speeds because of safety concerns. If passengers walk on the moving sidewalk at 230 ft/min, the resulting cumulative speed is 330 ft/min. A discussion of pedestrian walking speeds is provided by Fruin (*1*).

Moving sidewalk system capacity is a function of speed and passenger density on the treadway. For a 39-in. treadway width, a speed of 100 ft/min, and 2.5 ft^2 per standing passenger, the calculated ideal system capacity is 7,800 passengers per hour per direction. Some suppliers suggest that higher capacities with greater passenger densities are achievable. However, 2.5 ft^2 per passenger, especially if luggage or other carry-on articles are included, is considered to be a practical minimum (unpublished data, Lea + Elliott, 1988). Given slight pauses in the boarding of moving sidewalks and greater space allocations for those who walk rather than ride, practical maximum system capacity is about 5,000 passengers per hour per direction.

Courtesy Carts

Battery-powered, electrically propelled courtesy carts are used in many airline terminals for the transportation of passengers. These rubber-tired, driver-steered vehicles are supplied by the manufacturers of golf carts.

Cart capacity ranges from five to about nine passengers with carry-on articles plus driver. Maximum speed is approximately 9.5 mph. However, practical safe operating speed in a terminal environment is usually considerably less—about 3 to 5 mph (on the basis of field observations by Lea + Elliott staff). Operational endurance between out-of-service periods for battery recharging varies widely depending on usage. A full battery recharge requires 8 to 12 hr.

Courtesy carts, which are highly maneuverable, do not operate in an exclusive right-of-way. They typically share the terminal concourse floor with pedestrians, stopping as needed for passenger boarding and deboarding. The drivers maneuver their vehicles to avoid pedestrians, furniture, fixtures, and building components such as doors and partitions.

Service is provided in two ways. Carts are usually used to accommodate (*a*) mobility-impaired passengers who cannot walk long distances or whose walking speeds are well below normal and (*b*) passengers making close connections between flights, when even above-normal walking performance would not be sufficient.

Cart service is provided on a more organized basis over a defined route in at least one case. American Airlines uses a fleet of 16 carts in its east side terminal complex at Dallas–Fort Worth International Airport. That operation will be discussed in more detail later in this paper.

Buses

Buses are rubber-tired, driver-steered vehicles operating mostly on streets and roads in mixed traffic. At airports, they typically operate on terminal frontage and circulation roadways on a nonexclusive basis, sharing the right-of-way with other automotive vehicles. However, an exclusive right-of-way or dedicated high-occupancy vehicle lane may also be used. Curbside stops are defined but can easily be changed, and either scheduled or on-demand service is provided.

Speeds are influenced by roadway design, dwell time at the stops, and traffic congestion. Because of the relatively low speed performance of airport roadways, vehicle design is usually not a constraining speed factor. Vehicle capacity for buses in airport service is within a nominal range of 15 to about 60 passengers. Most buses are powered by diesel engines.

System capacity, which is a function of headway (time interval between buses) and individual bus capacity, can vary widely from a few hundred to about 1,500 passengers per hour per direction.

APMs

An APM is a class of public transit characterized by

- Automatic (driverless) control,
- Discrete vehicles that operate on exclusive rights-of-way and have nominal capacities of 10 to about 100 passengers,
- The use of a guideway to control the path of the vehicles,
- Maximum speeds of 8 to 50 mph, and
- System capacities ranging from 1,000 to 14,000 passengers per hour per direction.

Moving sidewalks, escalators, and elevators, although sometimes referred to as people movers, do not fit the foregoing description.

APMs are proprietary systems, and many technological features, such as propulsion, suspension, and control subsystems, vary considerably between suppliers.

Four types of APM configurations, shown in Figure 2, are usually considered for airport applications:

1. Single-lane shuttle: One train moves back and forth on a single guideway lane. The train reverses direction at each end-of-line station.
2. Dual-lane shuttle: There are two independent guideway lanes. One train on each lane moves back and forth, reversing direction at each end-of-line station. To provide the highest level of service, the train movements are synchronized.
3. Bypass shuttle: There is a single guideway lane with a short dual section to allow trains to pass each other. Two trains move back and forth, reversing direction as explained above.
4. Pinched loop: Two parallel guideway lanes connected at each end by crossovers form a collapsed loop. Trains cross

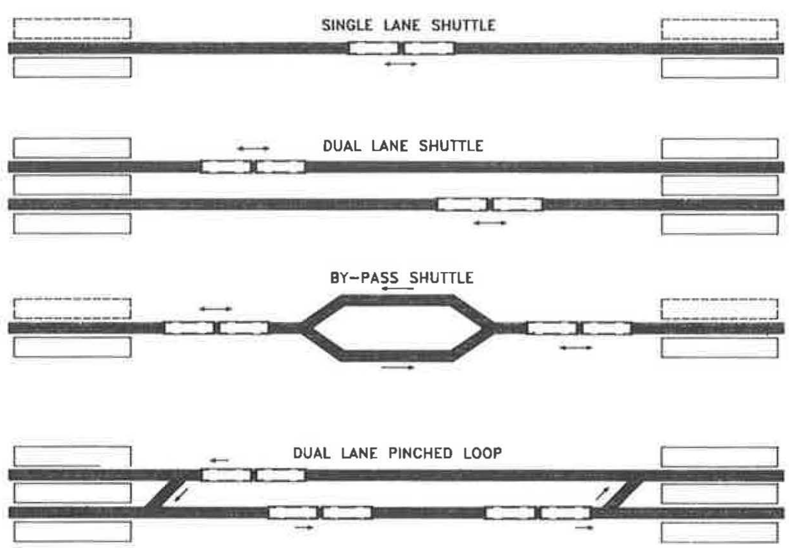

FIGURE 2 APM configuration concepts.

from one guideway lane to the other and reverse direction. The loop configuration permits more than two trains to operate at one time. The pinched loop can also operate as a single- or dual-lane shuttle.

Dual-lane shuttle and dual-lane pinched-loop configurations are most common at airports because they offer frequent service, high capacity, and inherent reliability compared with single-lane or bypass configurations.

Figure 2 shows linear alignments. However, APMs operate successfully with horizontal curves with minimum radii of 100 to 200 ft.

MOVING SIDEWALKS

As discussed previously, moving sidewalks provide point-to-point transportation along straight lines at low speeds. A good moving sidewalk application is in the United Airlines terminal at San Francisco International Airport. The layout is shown in Figure 3.

The 100-ft/min tread speed compares poorly with maximum pedestrian walking speed, which is approximately 230 ft/min. If it is assumed that passengers walk on a moving sidewalk, the cumulative speed is 330 ft/min. However, moving sidewalks with standard 39-in. tread widths do not perform well with mixed standing and walking traffic. This limitation is especially significant in an airport environment because of luggage or other carry-on articles that most passengers have with them. For standees, these items are typically placed on the moving sidewalk tread next to the passenger. They make passing maneuvers by walkers, many of whom also have carry-on articles or luggage in their hands or on their shoulders, difficult.

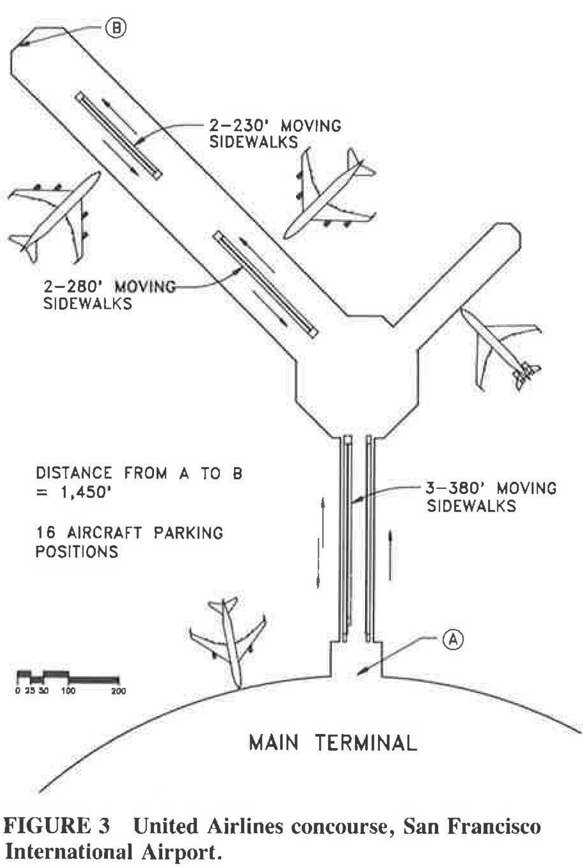

FIGURE 3 United Airlines concourse, San Francisco International Airport.

The approximate trip time to cover the 1,450 ft from Point A in the main terminal to Point B at the most remote United gate (see Figure 3) is 11.3 min if passengers do not walk on the moving sidewalk. That value was calculated by using 100 ft/min moving sidewalk speed and 230 ft/min walking speed. Associated walking distances are significant. Of the total 1,450-ft trip, about 560 ft (39 percent) is walked.

With moving sidewalks, access is continuous over time. Thus, frequency of service is not a factor unless there is a queue at the entry point, where passengers briefly pause when making the transition to the moving treadway.

Because the moving sidewalks are located on the concourse level and are a prominent linear element, oriented in the direction of travel, wayfinding is straightforward. The use of two moving sidewalks operating in the same direction in the connecting corridor between the main terminal and the concourse requires simple signs to explain usage.

As mentioned, luggage or carry-on article accommodation on moving sidewalks is a disadvantage in a walk left, ride right setup with the 39-in. tread width at San Francisco and in common use at other airports. Operation of parallel moving sidewalks in the same direction, as in the United connecting corridor, allows segregation of those wishing to walk and those wishing only to ride.

Persons in wheelchairs and most other mobility-impaired passengers are not able to use moving sidewalks. Some alternative form of transportation must be provided.

At operating speeds of 100 ft/min, moving sidewalks are perceived as being safe by almost all passengers. Because they are in plain view on the concourse level and lengths are limited by building codes, security is not a problem.

As is evident from Figure 3, moving sidewalks, because of their orientation and point-to-point nature, can be an inconvenient barrier to cross-concourse pedestrian movements. It is often necessary to walk around the end of a moving sidewalk and backtrack to one's destination. This feature is a particularly significant disadvantage at a connecting hub.

Architectural and structural integration into the terminal building is straightforward. It is good design practice to increase concourse width to take into account circulation space displaced by the moving sidewalk units.

Moving sidewalks are not flexible. Access points, locations, and lengths cannot be changed without major reconstruction and its attendant problems of interference with ongoing terminal operations.

Maintenance of moving sidewalks is not complex but does require careful planning. Routine and preventive maintenance is best accomplished at night, when the units can be taken out of service with minimal inconvenience to passengers. Any system stoppage during periods of terminal activity can cause major inconvenience to passengers, who must walk long distances unless there is a parallel unit operating in the same direction.

COURTESY CARTS

As discussed earlier, courtesy carts are used in two ways. They are most frequently provided on demand for the movement of mobility-impaired passengers whose walking capabilities are severely restricted and for other passengers making close connections. The services are almost always prearranged with and provided by the airlines or, in some cases, the airport operator.

This highly specialized service involves relatively few carts. They operate in mixed traffic with pedestrians on the aircraft boarding-deboarding level of the terminal. Because there are not many carts, traffic conflicts are not a serious problem. The carts are operated by airline or airport personnel assigned to furnish special services to passengers.

The second use of carts is a unique application in the American Airlines east side terminal complex at Dallas–Fort Worth International Airport. Figure 4 shows the layout of Terminals 2E and 3E, which are linked by a narrow connector building. The length of these facilities from the north end of Terminal 2E to the south end of Terminal 3E is 6,100 ft (1.15 mi). During connecting bank operations, approximately 12 carts are deployed to transport connecting passengers between arriving and departing flights. Although mobility-impaired passengers and others with close connections are given priority, cart service on a space-available basis is provided to anyone who wants it.

The circulation pattern followed by the cart drivers is based on the destinations of the passengers. Thus, from a system viewpoint, routes are random. However, an attempt is made to distribute the carts so that service to and from all gates is provided on a reasonably uniform basis.

There are no defined boarding or deboarding locations. Passengers access the carts much like roving taxis and are dropped off at their departure gates through notification to the driver.

On the basis of observations made by Lea + Elliott in 1988 with the assistance of American Airlines staff, the average system speed is between 3 and 5 mph. Using 4 mph as the average system speed and assuming steady-state cart flow from one end of the east side terminal complex to the other, cart headway is 2.9 min, producing a system capacity of only 187 passengers per hour per direction. Because of the stochastic nature of the cart system, frequency of service and system capacity calculations on a steady-state basis do not represent the actual quantity of service provided.

Cart service is not as reliable as other passenger mobility technologies that operate on a continuous or regularly scheduled basis. Obtaining a seat on a cart is similar to finding a vacant taxi during a peak period in the central business district of a large city.

Although passengers willingly use the carts, they are not popular. Nonusers often become annoyed with the carts during periods of congestion. The cart drivers compete for floor space with pedestrians. Because cart operations conflict with pedestrians, they create a significant safety risk.

Carts require no special building components other than parking places and sufficient electric circuit capability for battery recharge.

Like taxis, carts are flexible. Because there is no dedicated infrastructure, they can be deployed in a variety of ways and locations to meet passenger demands. Ability to accommodate growth in activity is, however, limited. Cart saturation is reached quickly, given pedestrian congestion on the shared terminal floor. Even with 12 operational carts in the 6,100-ft-long terminal complex, pedestrian-cart gridlock has been observed during busy periods.

American Airlines recognizes the limitations and disadvantages of the cart system. A program is under way to replace this stopgap measure with an upgraded APM, the AIRTRANS System, which currently operates in a right-of-way below the concourse level.

American also offers, as an alternative, bus service between Terminals 2E and 3E. The buses operate on terminal frontage and airport circulation roadways. Pickup and drop-off points are at the upper level terminal curb.

BUSES

Buses have been used at Honolulu International Airport for the past 27 years to transport passengers and employees. As shown in Figure 5, three separate terminals serve overseas, interisland, and commuter passengers. The Overseas Terminal consists of the Main Overseas Area, Diamond Head Concourse, Central Concourse, and Ewa Concourse.

The airport's Wiki Wiki Bus System is used to transport

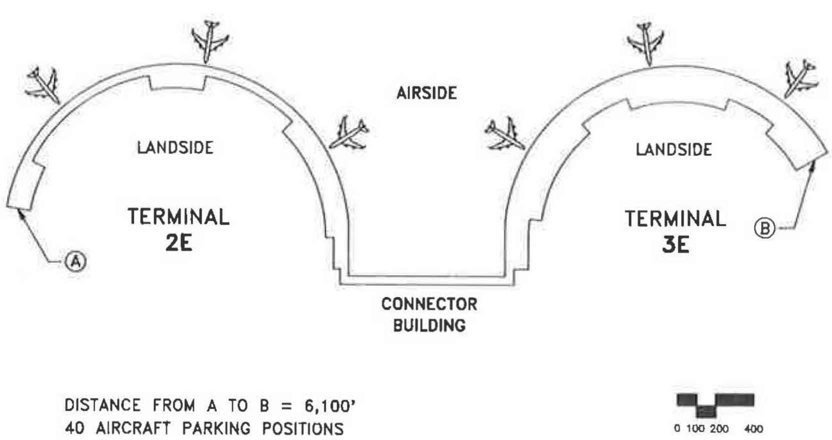

FIGURE 4 American Airlines east side terminal complex, Dallas–Fort Worth International Airport.

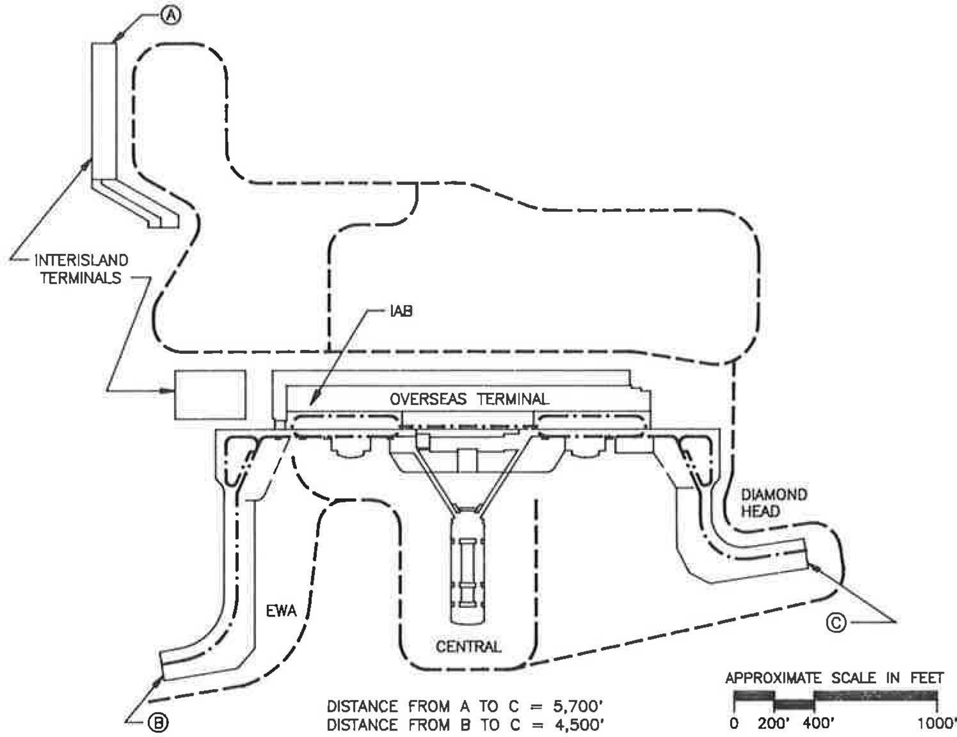

FIGURE 5 Wiki Wiki bus routes, Honolulu International Airport.

1. Arriving international passengers to the International Arrivals Building for border-crossing functions, including immigration, customs, agriculture, and public health (these passengers must remain separated from domestic passengers);
2. Arriving domestic passengers;
3. Connecting passengers; and
4. Departing passengers.

There is a complex series of routes involving mostly exclusive right-of-way on the landside and some apron level operations for hardstand aircraft positions. These routes are generally shown in Figure 5.

Wiki Wiki buses are specifically assigned to meet each arriving international and overseas domestic flight. By prearrangement, sufficient bus system capacity is allocated to match the number of deplaning passengers, all of whom must proceed to the FIS.

The other bus services are provided on a scheduled basis. The frequency of service depends on the time of day and demands placed on the system by international arrivals.

In 1988 the Wiki Wiki buses carried 5.3 million passengers, which was about 25 percent of total enplanements and deplanements for that year. Thus, the system is used extensively and is an integral aspect of the terminal complex.

An interesting feature of the Wiki Wiki buses is their ability to operate singly or in trains of up to three units. Currently there are 15 powered units and 21 trailers. Vehicle capacity is given in the following table:

	Passengers	
Description	*Seated*	*Standing*
Powered unit	17	13
Trailer	23	17

The total Wiki Wiki work force is composed of 67 persons, including 54 drivers. The fleet, routes, and number of stops have all increased as the airport has grown.

There is a wide disparity in the level of service. Arriving international and domestic passengers experience short waiting times because the buses meet their flights. On the other hand, interisland and other passengers experience a low level of service with long waiting times of as much as 20 min and circuitous routes.

The buses are not air-conditioned, and ride quality is similar to a city bus, with many starts, stops, and curves. In general, passenger comfort is low, especially when the buses operate at or near capacity. Many passengers, particularly those who are transferring or originating at Honolulu, choose to walk rather than use the Wiki Wiki buses.

APMs

APMs are currently in use at eight airports in the United States. Seven U.S. airport APMs are in various phases of system design, procurement, and implementation (*2*).

The APM currently being implemented at the new Denver International Airport is an excellent example of how this technology can be used when long distances are involved. Figure 6 shows the planned layout of the terminal facilities when the airport reaches its ultimate capacity of 55 million annual enplanements. An underground APM, operating in a pinched-loop configuration, will link the main terminal and the four airside concourses with each other. The distance from the center of the main terminal to the APM station in Concourse D, the most remote airside concourse, is 6,600 ft. The longest

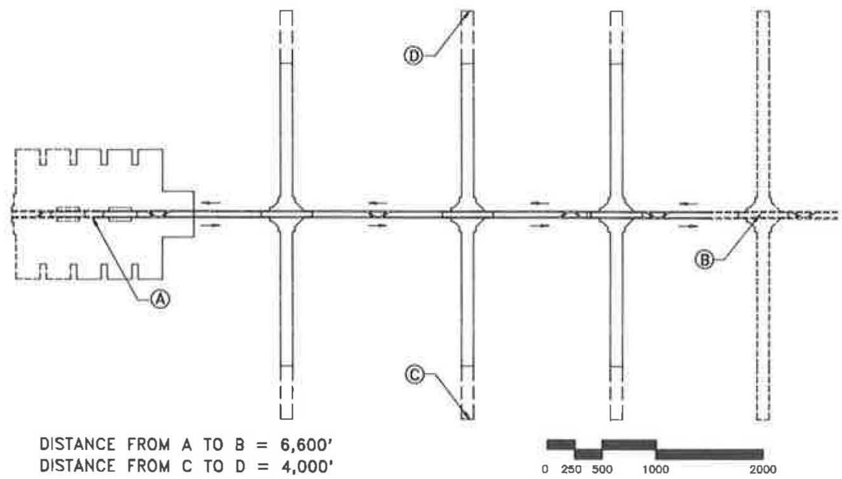

FIGURE 6 Automated ground transportation system, Denver International Airport.

passenger trip, from one end of Concourse D to the center of the main terminal, will be 8,600 ft (1.63 mi).

The APM will provide a high level of service to passengers, visitors, and airline and airport employees. Ultimate system capacity will be 12,900 passengers per hour per direction. Eight trains will operate on headways of 1.83 min. The maximum trip time from the main terminal to airside Concourse D (if the passenger just missed a train at the main terminal and therefore must wait one headway) will be 7.3 min. Average trip time (passenger waits one-half headway at main terminal station) will be 6.4 min.

The APM system design will provide a high level of reliability through the following features:

1. System component reliability and redundancy,
2. A sufficient number of spare vehicles to allow a comprehensive scheduled maintenance program,
3. Dual-lane guideway with end-of-line and intermediate crossovers to permit continued reduced-service operations should a train or guideway component become disabled for a prolonged period, and
4. A continuously available "hot standby train" that can replace a disabled train on short notice.

Passenger acceptance of airport APMs is generally high. The systems are fully accessible to the handicapped.

APMs have an outstanding safety and security record. Passengers perceive the systems to be safe and secure. Security features include on-board two-way voice communication between passengers and central control operators and CCTV on station platforms.

Because APMs operate in exclusive rights-of-way, vertical circulation requirements associated with stations are a significant facilities design feature. Both static and dynamic signs are typically used to aid the passenger wayfinding process.

An APM requires an exclusive right-of-way, stations, wayside equipment rooms, a central control area, and vehicle maintenance facilities. Most APMs are located on overhead structures or below grade in tunnels. Thus, significant facilities are associated with APMs, and attention to integration with other terminal elements and functions is an important consideration.

Many airport APMs are designed for future expansion. For example, the dashed lines on Figure 6 show how the Denver International terminal facilities and APM guideway will be expanded to include a fourth airside concourse. However, without adding guideway or stations, capacity can be increased by adding cars to trains and decreasing headway to a practical minimum of 90 to 100 sec. At Denver International, the initial system capacity of 6,000 passengers per hour per direction can be increased to 8,300 passengers per hour per direction by changing from two- to three-car trains.

Likewise, capacity can be decreased by using fewer trains at increased headway or by operating trains with fewer cars. At Denver International, fewer trains will be operated during late night and early morning hours, when ridership is expected to be only a small fraction of the peak requirement.

APM systems require a high level of maintenance. Through careful planning of facilities and operations, maintenance can be accomplished without affecting service. The ability of APMs to run at reduced levels of service assists in system maintenance.

SYSTEM EVALUATION CRITERIA

The previous sections have identified salient features of the four passenger mobility technologies, including advantages, disadvantages, and limitations. In this section evaluation criteria will be organized in an outline. The criteria can serve as a useful checklist for planners, designers, and operators of airport terminals who have responsibility for analyzing and making decisions about passenger mobility systems.

System Performance

The following performance criteria can be used to measure the functionality of the technologies:

1. Time consumed by the passenger in using the system, which is a function of the speed of the technology and other operating characteristics;
2. Frequency of service, also referred to as headway;

3. System capacity, usually measured in passengers per hour per direction; and
4. Reliability of service, a measure of system dependability.

Passenger Acceptance

Passenger acceptance, a key consideration, can be evaluated by using the following criteria:

1. Associated walking and vertical circulation requirements (vertical circulation includes stairways, elevators, and escalators);
2. Passenger wayfinding, accomplished through architecture and signs;
3. Luggage accommodations;
4. Use by handicapped persons;
5. Safety; and
6. Security.

Facilities Interfaces

Passenger mobility technologies cannot be considered as isolated systems. They must interface with the terminal buildings and related infrastructure. Evaluation criteria consist of

1. Constructibility,
2. Architectural and structural integration with other terminal components, and
3. Impacts on other terminal functions.

Flexibility

Given the dynamic nature of air transportation, assumptions about passenger mobility requirements are often uncertain and temporary. Flexibility criteria consist of (*a*) expandability to accommodate growth and (*b*) responsiveness to other changes in conditions.

Maintenance

Each of the mobility technologies requires varying types of maintenance. The criteria consist of (*a*) maintenance complexity and (*b*) impacts on service.

CONCLUSIONS

Moving sidewalks can be used effectively to aid passenger mobility when the total length of passenger movement does not exceed 1,000 to 1,500 ft. The slow treadway speed of 100 ft/min and the tendency to form barriers to cross-travel movements are distinct drawbacks. If walk left, ride right use is a serious design goal, either a 55-in. minimum treadway width or dual units operating in the same direction are essential. Moving sidewalks can only provide point-to-point travel along straight lines.

Limited numbers of courtesy carts serve an important role in assisting handicapped passengers and transporting passengers between flights when connecting times are close because of late aircraft arrivals. Because they operate in mixed traffic with pedestrians on the aircraft boarding-deboarding level of terminals, carts are not a viable transportation mode for significant ridership values. Carts should not be operated on fixed routes to transport large numbers of passengers on a regular basis. Carts offer flexibility that moving sidewalks and APMs do not, because they are maneuverable and do not require an exclusive right-of-way.

Buses for transporting connecting passengers between flights have several disadvantages. Because they operate from the terminal curb, they are not convenient. Passengers must pass through anti–air piracy screening on reentry because they leave the sterile area of the terminal. Bus operations involve circuitous routes in relation to passengers' arrival and departure gates. Average speed is low, and trip time is high, because of the shared right-of-way with other vehicular traffic and lengthy dwell times at stops. Poor bus productivity is exacerbated because traffic congestion related to origin-destination passengers occurs during the connecting bank, which is precisely when peak bus activity occurs.

The use of dedicated bus lanes or exclusive rights-of-way displaces valuable roadway space, and, for exclusive rights-of-way, involves high infrastructure costs.

APMs are best suited to relatively high ridership over route lengths in excess of 1,000 ft, though shorter alignments in specialized situations should not be ruled out. For example, a shorter APM could be useful to meet high peak ridership when time is critical. APMs offer a high level of schedule and trip time dependability because they use an exclusive right-of-way and their automated operation is not influenced by varying human skill levels associated with courtesy carts and buses.

APMs require careful attention to terminal architecture and structural engineering. Spatial and functional integration into the terminal facilities and related infrastructure is essential.

To effectively meet air travel demands of the 21st century, large airport terminal complexes will incorporate a combination of the mobility technologies discussed in this paper. When designed to act synergistically, these technologies, along with good planning, architecture, and engineering, will result in terminal facilities capable of meeting the challenges that lie ahead.

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Detroit Downtown People Mover Maintenance Data: An Overview

UTPAL DUTTA, RAMAKRISHNA REDDY TADI, AND MOHAMMAD S. KESHAWARZ

The Detroit Downtown People Mover (DPM) has been in operation since August 1987. The 1989 maintenance data of DPM were reviewed, and an attempt was made to determine the relationship between various entities of the DPM maintenance system. Peak failure was observed during December, so winter might have played a significant role in the life cycle of components. Almost equal numbers of repairs were made for each train, with one exception. The train control component was the component most frequently repaired.

The Detroit Downtown People Mover (DPM) has been in operation since August 1987. The DPM is operated and maintained under a set of rules different from those governing other mass transit systems, such as bus, subway, and so forth. The maintenance record of DPM during 1989 is reviewed, and interesting nomenclature associated with DPM maintenance is highlighted.

BACKGROUND

The Detroit Transportation Corporation (DTC) owns and operates the DPM. Construction began in October 1983 on the 2.9-mi (4.6-km), $200.3 million project with 80 percent federal and 20 percent state funding. When the project was opened for revenue service in July 1987, it became the second of its kind in a North American city (Miami's was the first). The DPM, which is one of the most technologically advanced transportation systems in the world, has 13 stations (*1*).

The vehicles on the single-track loop system run in one direction (counterclockwise). Round-trip time is approximately 14 min, with 2- to 3-min headways. The DPM operates 7 days a week. Its operating hours are as follows:

Day	*Hours*
Monday–Thursday	7:00 a.m.–11:00 p.m.
Friday	7:00 a.m.–midnight
Saturday	9:00 a.m.–11:00 p.m.
Sunday	Noon–8:00 p.m.

A computerized control center operates the rail system, monitoring the location of each vehicle at all times. Linear induction motors propel the cars. Each car accommodates 34 passengers seated and 66 standing. DTC currently owns 12 trains.

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ORGANIZATIONAL STRUCTURE OF DPM

The day-to-day management of DPM is carried out by the Operation and Maintenance (O&M) division. The O&M division consists of three subdivisions. The breakdown of personnel by subdivision is given in Table 1.

Maintenance of DPM is performed mostly by O&M personnel. The cost averages approximately $450,000 per month, an annual rate of about $5.5 million (*2*). The trains are subject to routine maintenance monthly or every 4,000 mi (whichever comes first). However, in the absence of detailed information on vehicle miles traveled by each train before failure, various analyses were conducted on a monthly basis only. The ratio of scheduled routine maintenance to unexpected maintenance is 3.5 to 1 (*3*).

Maintenance activities are mostly scheduled and monitored by the maintenance scheduling department of the O&M division. The maintenance facility is located next to Times Square Station and includes two maintenance bays each capable of holding three trains for all vehicle maintenance; an automatic train control laboratory with first-, second-, and some third-level repair equipment; and an electronics laboratory with test setups for fare collection, vehicle doors, closed circuit television, on-board communication, and propulsion. General work areas for steam cleaning, welding, and drilling are also provided. The facility runs 24 hr per day and consists of three shifts: 7:30 a.m.–3:30 p.m. (Shift 1), 3:30 p.m.–11:30 p.m. (Shift 2), and 11:30 p.m.–7:30 a.m. (Shift 3).

Most repairs other than services warranted by the manufacturer are performed in-house. The location of various maintenance activities is shown in Figure 1.

RELATIONSHIP BETWEEN DPM AND DIFFERENT ACTIVITIES

A people mover may be classified into one of three types: active (operative and in service), transitional (operative and in service by means of a redundant system), or failed (not in operation because of prime or redundant system failure). The day-to-day status of a train in relation to the maintenance facility can be described as follows:

1. An "active" people mover is in service.
2. When a problem arises, the maintenance facility is informed. Switch to redundant system if possible and keep running, or tow the failed system to the maintenance facility.

TABLE 1 PERSONNEL BREAKDOWN BY DIVISION (3)

Division	Subdivision	Total Staff in Subdivision	No.	Category
Operation and Maintenance	Operations	15	1 5 9	Manager Supervisors Control Operator
	Maintenance	39	1 5 13 10 8 1 1	Manager Supervisors Electronic Technicians Mechanical Technicians Utility Worker Maintenance Schedule Date Clerk
	Administration	7	1 1 3 1 1	Manager Supervisor Store Keeper Accounting Administrator

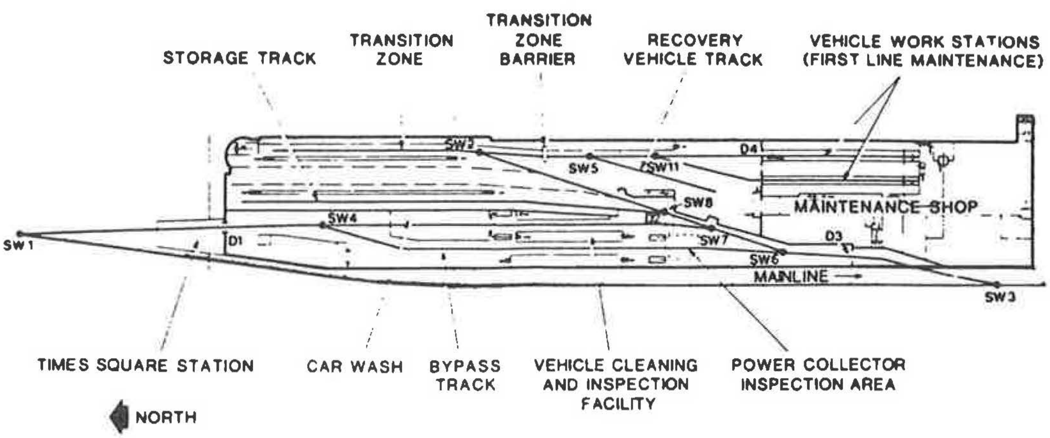

FIGURE 1 DPM maintenance facility.

3. A quick-repair person (QRP) is on the train while the train is still running.
4. The QRP inspects the failed item and if possible repairs or replaces it.
5. If the QRP cannot repair or replace the failed item on the train, the train is still running on a redundant system.
6. At the end of the day, the train returns to the service station for preventive maintenance.
7. In the maintenance facility each train is categorized as follows: requires preventive maintenance to be scheduled during Shifts 1, 2, or 3; failed components to be repaired internally during Shifts 1, 2, or 3; or failed component is warranted and will be repaired by the manufacturer.
8. Repair work is being documented.
9. Train is returned to service.

A schematic diagram of the day-to-day DPM activities is presented in Figure 2.

DESCRIPTION OF DPM MAINTENANCE SYSTEM

DPM maintenance data are stored in a mainframe computer. Typical maintenance data include work order number, train number (there are 12 trains providing daily service), date work was performed, shift during which the work was performed, name of the mechanic, and codes representing the type of work that was performed (reason, item, and action codes). For example, C is a reason code indicating corrective maintenance, BM is a component code indicating battery monitor, and R is an action code indicating repaired. Therefore, C BM R means that a defective or malfunctioning battery monitor was repaired on the vehicle shown in the train number field.

The O&M division keeps track of repair work by assigning codes given in Tables 2 to 5.

REVIEW OF 1989 DPM MAINTENANCE DATA

Maintenance records of DPM were obtained from DTC. Type of component failure, train number, shift, and repair action information were coded and keyed into the computer. SPSS software was used to determine the relationship between various elements of DPM maintenance activities. Characteristics of DPM maintenance data are presented and discussed in the following sections.

Frequency of Repairs by Month

During 1989, 5,374 repairs were done on the 12 trains. Numbers of repairs by month and by train are shown in Figures 3 and 4 and Table 6. The data indicate that the month with the largest number of repairs was December (727, or 13.3 percent of all repairs), followed by August (666, or 12.4 percent). The month with the smallest number of repairs was February

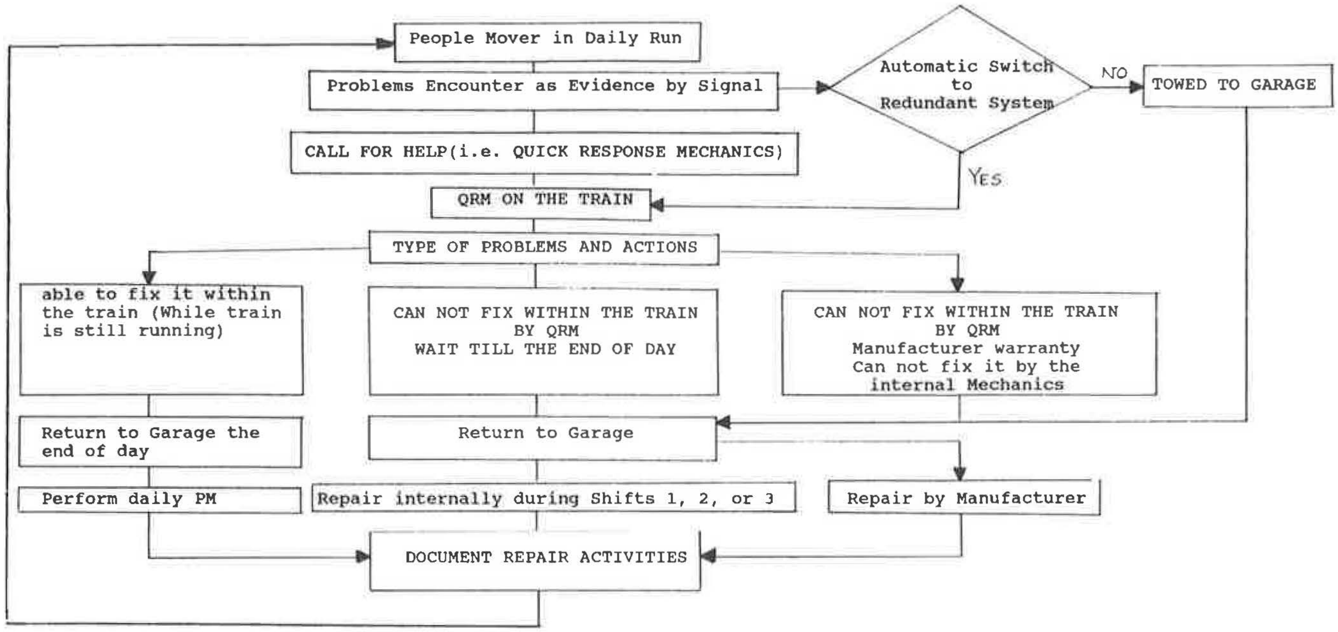

FIGURE 2 Day-to-day status of DPM.

TABLE 2 TRAIN CODE

TRAIN VEHICLE #	CODE
1	V1
2	V2
3	V3
4	V4
5	V5
6	V6
7	V7
8	V8
9	V9
10	V10
11	V11
12	V12

(263, or 4.9 percent), followed by April. In January the train with the highest number of repairs was Train 5. In February, May, and September it was Train 3; in March and April it was Train 10; in June and December it was Train 6; in July and October it was Train 12; in August it was Train 9; and in November it was Train 11.

Frequency of Repairs by Shift

Data were studied to determine whether any relationship exists among numbers of repairs by month, train, and shift. The findings are given in Tables 7 and 8 and in Figures 5 and 6. A review of Tables 7 and 8 indicates that 48 percent of the repairs were done during Shift 3, followed by Shift 1 (39.3 percent) and Shift 2 (12.7 percent). The train with the largest number of repairs was Train 9 (503 repairs), followed by Train 12 (480) and Train 7 (475). The largest percentage of repairs was done during Shift 3 on Train 3, during Shift 2 on Train 2, and during Shift 1 on Train 6. For Shift 3 the month with the most repairs was March, followed by August and December. For Shift 2 it was November, and for Shift 1 it was December.

TABLE 3 REASON CODE

CODE	DESCRIPTION
P	PREVENTIVE MAINTENANCE (PM)
C	CORRECTIVE MAINTENANCE
I	INCORRECT MAINTENANCE
R	ROUTINE MAINTENANCE
Z	SUBSEQUENT FAILURE
J	COMSYST NO RESPONSE
B	INTERMITTENT FAILURE
N	SCHEDULED PM INSPECTION
D	TESTING INDUCED
W	WAYSIDE INDUCED
K	PATRON INDUCED
T	TRAIN INDUCED
M	MODIFICATION
H	ALARM
G	INFO/DATA
O	STARTER
V	VANDALISM
X	ACCIDENT
S	SEASONAL
F	FAILURE
A	ACCESS
E	TIMEOUT
L	LOOSE
Q	GROUND FAULT

TABLE 4 ACTION CODE

Code	DESCRIPTION
F	FINISHED
I	INSPECT
R	REPAIR
C	CLEAN
T	TEST
M	MODIFY
P	ASSIST
Q	INSTALL
L	LUBRICATE
E	EXCHANGE
A	ADJUST
X	RESET
H	HOLD
K	TAG OUT
D	DATA DUMP
N	NO FAULT FOUND
G	SPECULATION
U	UNFINISHED
I	INVENTORY
B	BLEED SYSTEM
W	AWAITING PARTS
O	RIDE VEHICLE

TABLE 5 COMPONENT CODE

CODE	NAME OF COMPONENT
BM	BATTERY MONITOR
CB	CARBODY
CM	COMMUNICATION
CP	COUPLER
DB	DISC BRAKE
DC	CONVERTER
ED	END DOORS
EL/IL	EXTERIOR/INTERIOR LIGHTING
HA	HVAC
HM	HEALTH MONITOR
L	INTERIOR LIGHTING
PC	POWER COLLECTOR
PD	PASSENGER DOOR
PR	PROPULSION
PV	PARTIAL VEHICLE INSPECTION
TB	TRACK BRAKE
TC	TRAIN CONTROL
TR	TRUCK
VE	VEHICLE ELECTRONICS

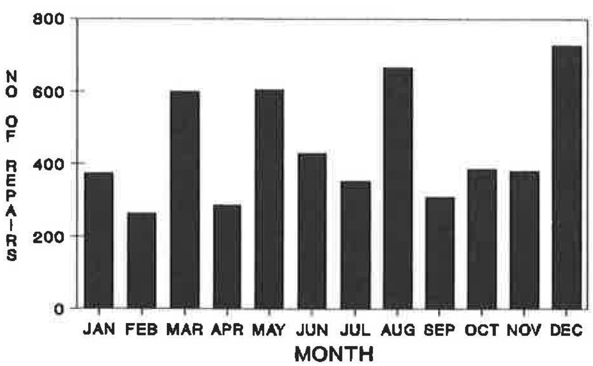

FIGURE 3 Frequency of repairs by month, 1989 DPM maintenance data.

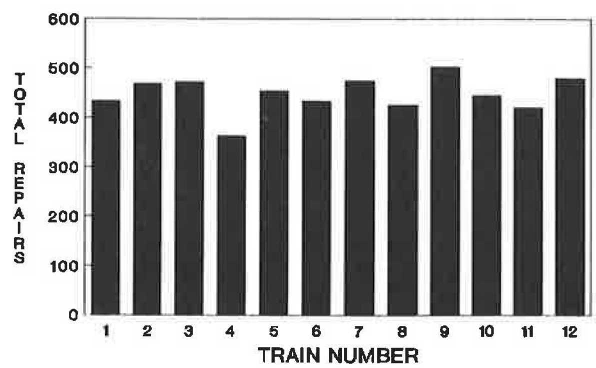

FIGURE 4 Frequency of repairs by train, 1989 DPM maintenance data.

TABLE 6 REPAIR FREQUENCY FOR 1989 BY TRAIN AND MONTH

Train#	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1	33	9	47	15	53	33	33	78	18	30	38	46	433
2	30	22	54	27	50	38	43	34	40	26	20	84	468
3	14	54	69	13	78	19	20	53	41	36	27	48	472
4	21	13	39	31	31	32	20	44	32	27	20	53	363
5	44	30	39	27	37	38	36	37	28	30	41	67	454
6	39	19	27	24	43	50	20	57	24	23	22	86	434
7	34	28	65	26	47	47	28	48	25	37	28	62	475
8	40	20	54	31	36	31	15	57	18	37	19	68	426
9	26	20	41	25	64	35	36	101	19	27	35	74	503
10	13	18	88	31	60	39	22	42	18	39	19	56	445
11	38	8	40	14	54	35	33	60	13	24	62	40	421
12	41	22	36	21	51	33	47	55	32	49	50	43	480
Total (%)	373 (6.9)	263 (4.9)	599 (11.1)	285 (5.3)	604 (11.2)	430 (8.0)	353 (6.6)	666 (12.4)	308 (5.7)	385 (7.2)	381 (7.1)	727 (13.5)	5374

TABLE 7 DPM REPAIRS FOR 1989 BY MONTH AND SHIFT

Month	Shift 1 No. (%)	Shift 2 No. (%)	Shift 3 No. (%)	Total
January	110(29.5)	14(3.8)	249(66.8)	373
February	54(20.5)	23(8.7)	186(70.7)	263
March	160(26.7)	81(13.5)	358(59.8)	599
April	108(37.9)	58(20.4)	119(41.8)	285
May	328(54.3)	29(4.8)	247(40.9)	604
June	228(54.3)	21(4.9)	181(42.1)	430
July	156(44.2)	51(14.4)	146(41.4)	353
August	218(32.7)	101(15.2)	347(52.1)	666
September	106(34.4)	55(17.9)	147(47.7)	308
October	177(46.0)	68(17.7)	140(36.4)	385
November	138(36.2)	117(30.7)	126(33.1)	381
December	328(45.1)	65(8.9)	334(45.9)	727
Total	2111(39.3)	683(12.7)	2580(48.0)	5374

TABLE 8 REPAIR FREQUENCY FOR 1989 BY TRAIN AND SHIFT

Train	Shift 1 No. (%)	Shift 2 No. (%)	Shift 3 No. (%)	Total
1	155(35.8)	65(15)	213(49.2)	433
2	191(40.8)	69(16.7	208(44.4)	468
3	147(31.1)	63(13.3)	262(55.5)	472
4	148(40.8)	49(13.5)	166(45.7)	363
5	183(40.3)	48(10.6)	223(49.1)	454
6	210(48.4)	34(7.8)	190(43.8)	434
7	167(35.2)	60(12.6)	248(52.2)	475
8	173(40.6)	57(13.9)	196(46.0)	426
9	181(36.0)	67(13.3)	255(50.7)	503
10	194(43.6)	49(11.0)	202(45.4)	445
11	173(41.1)	56(13.3)	192(45.6)	421
12	189(39.4)	66(13.8)	225(46.9)	480
Total	2111(39.3)	683(12.7)	2580(48.0)	5374

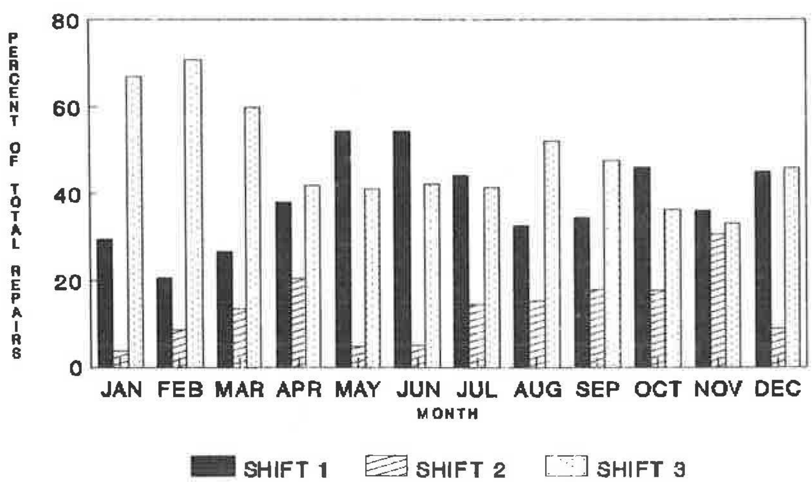

FIGURE 5 Repairs by month and shift, 1989 DPM maintenance data.

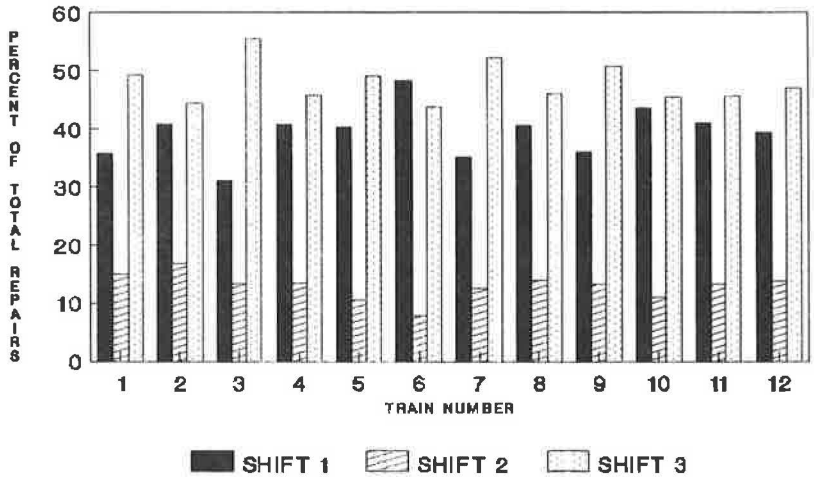

FIGURE 6 Repairs by train and shift, 1989 DPM maintenance data.

Component Failure by Train, Shift, and Month

Maintenance data were stored in 19 component categories in the data base (see Table 5). The data were reviewed to determine the number of repairs by component type. The findings of this analysis are presented in Tables 9 and 10 and in Figure 7. A plot of component type versus mean time between failures is shown in Figure 8. Tables 9 and 10 and Figure 8 indicate that TC was the component that failed most frequently (1,078 times), followed by PR (913 times) and TR (562 times). The shortest mean time between failures was observed for TC (0.58 weeks), followed by PR (0.68 weeks). In Shift 1, TC was repaired or replaced 456 times. TC was also the most frequently failed component in Shift 2. In Shift 3 PR was the most frequently failed component (552 times). TC was responsible for most of the failures on Trains 1 (112, or 25.9 percent), 2 (97, or 20.7 percent), 3 (79, or 16.7 percent), 4 (77, or 22.2 percent), 6 (78, or 18.0 percent), 7 (102, or 21.5 percent), 8 (76, or 17.8 percent), 10 (93, or 20.9 percent), 11 (87, or 20.7 percent), and 12 (122, or 25.4 percent). PR was the most frequently failed component for Trains 5 (99, or 21.8 percent) and 9 (140, or 27.8 percent).

SUMMARY OF FINDINGS

The DPM is an "activity center circulation" system, significantly different from a conventional line-haul transit facility in its use (*3*). Using the year of data, various relationships among the elements of maintenance activities were reviewed and analyzed for this unique transportation system. The conclusions are as follows:

1. The month with the largest number of repairs was December (727), mostly in Shifts 1 and 3, followed by August (666). The largest number of repairs may be in December because of severe winter weather conditions.
2. The shift with the largest number of repairs was Shift 3 (48 percent). This appears logical because most of the trains are not in service during Shift 3.

TABLE 9 REPAIR FREQUENCY FOR 1989 BY COMPONENT TYPE AND SHIFT

Component-Type	Shift 1 No. (%)	Shift 2 No. (%)	Shift 3 No. (%)	Total No. (%)
BM	52(35.1)	19(13.3)	74(51.7)	145(2.7)
BP	0	0	2(100)	2(0.0)
CB	65(60.2)	11(10.2)	32(29.6)	108(2.0)
CM	38(21.8)	45(25.9)	91(52.3)	174(3.2)
CP	103(56.3)	13(7.1)	67(36.6)	183(3.4)
DB	188(37.1)	39(7.7)	280(55.2)	507(9.4)
DC	66(51.6)	19(14.8)	43(33.6)	128(2.4)
ED	39(50.6)	10(13.0)	28(36.4)	77(1.4)
HA	160(44.9)	47(13.2)	149(41.9)	356(6.6)
HM	18(27.7)	15(23.1)	32(49.2)	65(1.2)
PC	21(30.4)	0(0.0)	48(69.6)	69(1.3)
PD	93(24.8)	42(11.2)	240(64.0)	375(7.0)
PR	302(33.1)	59(6.5)	552(60.5)	913(17.0)
TB	67(48.6)	13(9.4)	58(42.0)	138(2.6)
TC	456(42.3)	280(26.0)	342(31.7)	1078(20.1)
TR	262(46.6)	36(6.4)	264(47.0)	562(10.5)
VE	107(61.1)	18(10.3)	50(28.6)	175(3.3)
EL/IL	74(23.2)	17(5.3)	228(71.5)	319(5.9)
Total	2111(39.3)	683(12.7)	2580(48.0)	5374

TABLE 10 REPAIR HISTORY BY COMPONENT TYPE AND TRAIN

TRAIN#	REPAIR FREQUENCY/PERCENT BY COMPONENT TYPE																	
	BM	BP	CB	CM	CP	DB	DC	ED	HA	HM	PC	PD	PR	TB	TC	TR	VE	EL/IL	TOTAL
1	2 .5	-	10 2.3	17 3.9	12 2.8	30 6.9	7 1.6	1 .2	25 5.8	8 1.8	6 1.4	46 10.6	57 13.2	9 2.1	112 25.9	47 10.9	12 2.8	32 7.4	433
2	20 4.3	-	11 2.4	17 3.6	13 2.8	51 10.9	7 1.5	8 1.7	24 5.1	11 2.4	4 .9	43 9.2	73 15.6	10 2.1	97 20.7	38 8.1	16 3.4	25 5.3	468
3	4 .8	-	13 2.8	16 3.4	18 3.8	51 10.8	5 1.1	16 3.4	34 7.2	7 1.5	3 0.6	17 3.6	107 22.7	16 3.4	79 16.7	44 9.3	17 3.6	25 5.3	472
4	11 3.1	-	12 3.3	12 3.3	13 3.6	20 5.5	7 1.9	6 1.9	28 7.7	-	6 1.7	26 7.2	43 11.8	11 3.0	77 21.2	58 16.0	9 2.5	24 6.6	363
5	16 3.5	2 .4	7 1.5	21 4.6	13 2.9	34 7.5	7 1.5	6 1.3	39 8.6	9 2.0	4 .9	31 6.8	99 21.8	12 2.6	68 15.0	44 9.7	16 3.5	26 5.7	454
6	10 2.3	-	7 1.6	11 2.5	21 4.8	57 13.1	14 3.2	3 .7	34 7.8	4 .9	8 1.8	28 6.5	74 17.1	7 1.6	78 18.0	39 9.0	15 3.5	24 5.5	434
7	13 2.7	-	8 1.7	14 2.9	15 3.2	37 7.8	22 4.6	4 .8	26 5.5	7 1.5	4 .8	42 8.8	80 16.8	13 2.7	102 21.5	40 8.4	22 4.6	26 5.5	475
8	29 6.8	-	10 2.3	7 1.6	16 3.8	47 11.0	27 6.3	4 0.9	26 6.1	1 .2	7 1.6	31 7.3	51 12.0	14 3.3	76 17.8	43 10.1	9 2.1	28 6.6	426
9	19 3.8	-	10 2.0	15 3.0	19 3.8	30 6.0	9 1.8	6 1.2	31 6.2	3 0.6	9 1.8	38 7.6	140 27.8	7 1.4	87 17.3	45 8.9	10 2.0	25 5.0	503
10	4 0.9	-	4 0.9	15 3.4	9 2.0	60 13.5	8 1.8	6 1.3	33 7.4	5 1.1	8 1.8	25 5.6	64 14.4	11 2.5	93 20.9	56 12.6	17 3.8	27 6.1	445
11	9 2.1	-	6 1.4	17 4.0	11 2.6	48 11.4	10 2.4	8 1.9	35 8.3	6 1.4	6 1.4	25 5.9	40 9.5	11 2.6	87 20.7	56 13.3	13 3.1	33 7.8	421
12	8 1.7	-	10 2.1	12 2.5	23 4.8	42 8.8	5 1.0	9 1.9	21 4.4	4 0.8	4 0.8	23 4.8	85 17.7	17 3.5	122 25.4	52 10.8	19 4	24 5	480

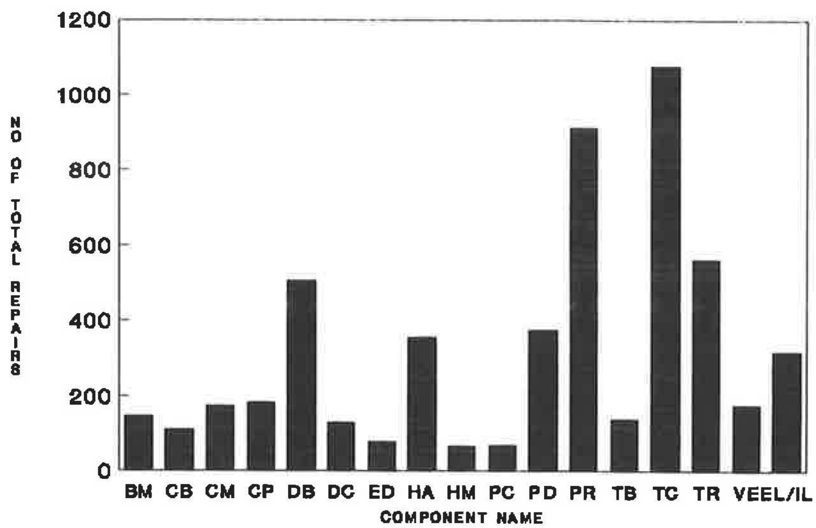

FIGURE 7 Repairs by component type, 1989 DPM maintenance data.

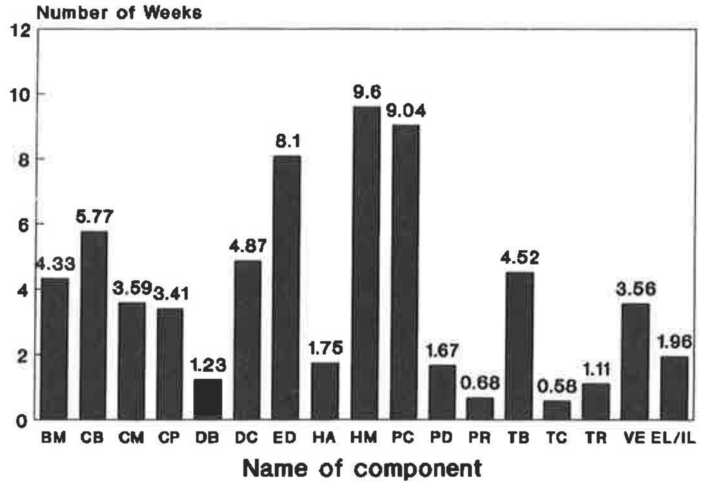

FIGURE 8 Mean time between failures, 1989 DPM maintenance data.

3. Because the smallest number of repairs was done during Shift 2, it is recommended that repairs be limited to Shifts 1 and 3. Thus, as a cost-saving measure, Shift 2 could be eliminated. However, the implications on labor relations should be fully explored before closing Shift 2.

4. Except for Train 4, which had the fewest repairs (363), trains had almost equal numbers of repairs (see Figure 4). Maintenance data for 1989, which is almost 2 years after the initiation of the DPM, were reviewed. Thus, the data represent the steady-state condition of the failure curve. The steady-state condition was evident from the almost equal number of repairs for all trains.

5. TC was the most frequently failed component (1,078 times), followed by PR and TR. Sufficient stocks of these components should be maintained. It is recommended that most emphasis be placed on TC.

Operating cost data could not be obtained. In addition, the time between failure and repair was not kept by the DPM authority, so no attempt was made to study downtime and cost factors.

For further research, it is recommended that the cost of component failure be considered (if cost data are available) and that the most cost-effective maintenance strategy be identified. This could save thousands of dollars, create a positive image of this state-of-the-art technology, and encourage other cities to consider such a circulation system.

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