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Part 2—Operations and Technology

Foreword

This volume highlights the expansion of research interest in the technical side of transit. The subjects discussed represent almost all facets of the field in a variety of transit settings. The papers are based on presentations at TRB's 1993 Annual Meeting, and each has been reviewed by peers in the field of transit, both practitioners and academics.

In Part 1, eight areas of current research interest are addressed. Farkas discusses reverse commuting, a need that reflects today's reality that new jobs are in the suburbs and many workers are in the city. Bell describes transit funding in Japan, and Peskin et al. show how privatization in the United States has helped relieve financial pressures in Denver, Colorado. More agencies are applying strategic planning, service coverage optimization, and corridor ridership forecasting, subjects addressed by Boyle and Ouderkirk, Spasovic and Schonfeld, and Eash et al., respectively. Ambruso investigates the cost-effectiveness of marketing transit by direct mail, and Everett and Ozanne relate the impact of transportation demand management techniques on marketing.

Part 2 reviews eight subjects that investigate the delivery of transit to the customer. Two basic matters of growing concern are the role of transit in the spread of crime, examined by Plano, and system guidelines for transit security, presented by Balog et al. Yee uses a computer model to determine the optimal crew size for fare collection, Huang and Smith report on a case study to develop cost-effective ride check procedures, and Furth and Kumar study ways to sample barrier-free ridership. Finding the optimal size of an operating work force is part of the desire to determine labor needs, and Shiftan and Wilson discuss the effects of overtime on such a model. Finally, Black attempts to identify rural public transit needs, and Erera and Kornhauser apply computer technology to the design of advanced transit systems.

These papers strongly suggest that transit research is pushing at the boundaries of current knowledge. The ideas, models, and techniques presented in this Record have real-world transit application. Transit policy makers, executives, managers, and staff, along with transit researchers, will find valuable material here. The information sets the stage for further exploration and analysis.

PART 1

Planning and Marketing

Factors of Successful Private-Sector Reverse Commute Services

Z. ANDREW FARKAS

The suburbanization of employment in metropolitan areas has opened up new markets for private-sector reverse commute services. FTA initiated the Entrepreneurial Services Challenge Grant Program (ESP) to promote such services, yet the factors leading to successful services have not been identified. The objective of the research is to identify and examine the market, service provision, financial, managerial, and organizational factors that characterize successful services. A literature review and three case studies of successful private-sector reverse commute services in large metropolitan areas were conducted. The characteristics of successful private-sector reverse commute services are (a) a lean management structure with dynamic entrepreneurship and communication; (b) strategies emphasizing financial flexibility and marketing (market research to identify promising market niches and promotion that emphasizes cost savings to employers); (c) establishment of contracts with employers for subsidized transportation and matching of jobs with labor; (d) close relationships with employment, training, and recruitment organizations; (e) comprehensive screening of commute service employees; and (f) monitoring of performance. As a means to promote such services, FTA should implement a training and long-term technical assistance component to complement the financial assistance of ESP.

The suburbanization of employment in metropolitan areas has opened up markets for private-sector reverse commute services. Although suburban employers often experience labor shortages, large numbers of inner-city residents remain unemployed. Public mass transit systems have been unable to link city residents conveniently and cost-effectively to suburban areas, where economic activities are highly dispersed. As a result, some entrepreneurs in a few cities have established services that transport inner-city residents to suburban employment opportunities.

A detailed study of the Baltimore metropolitan area indicated that employment decentralization, low rates of automobile ownership, and inconvenient transit services contribute to declining job accessibility for inner-city residents who earn low wages (*1*). Travel times on public transit for reverse commutes are often significantly longer than for commutes oriented toward the central business district, and the accessibility by transit to suburban activity centers from several areas of the city is low. In addition, there are few reverse commute service options: they consist essentially of public mass transit and private automobiles or taxis.

In an attempt to mitigate similar conditions in many U.S. cities, FTA initiated the Entrepreneurial Services Challenge Grants Program (ESP). ESP was established in 1988 to promote the development of entrepreneurial services that use little or no subsidy to supplement mass transit systems. ESP grants were intended as seed money to assist private operators—particularly small, minority, and disadvantaged businesses—with capital acquisitions, technical planning, and marketing activities. It has supported various organizations such as inner-city civic groups, private-sector transportation providers, and local employers and developers that have attempted new services.

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HYPOTHESIS, OBJECTIVE, AND METHODOLOGY

In the few cities that have private-sector reverse commute services, the factors leading to successful operation have not been identified. Adequate financial resources are thought to be critical to any small enterprise. Yet unique market, service provision, managerial, and organizational factors are also fundamental to successful private-sector reverse commute services. The objective of this research is to identify and examine the factors that characterize such services.

A literature review and three case studies of successful private-sector reverse commute services in large metropolitan areas were conducted. Success was not defined in terms of stringent financial criteria because of the small number of private-sector reverse commute services, their recent beginnings, the variety of organizations and service objectives, and the different scales of operation. Successful services were those that had at least 1 year of operations experience, were thriving and expanding operations, and were described by FTA staff as well-managed organizations. The literature review sought to define the factors to be evaluated in the case studies.

The cases selected are Accel Transportation, of Chicago; Accessible Services, Inc., of Philadelphia; and Central Transit System, of Orlando, Florida. These cases were evaluated using available documents and publications and face-to-face interviews with the top manager of each of the three organizations. The interviews were conducted using a prepared questionnaire.

LITERATURE REVIEW

In an attempt to improve the accessibility of inner-city residents to jobs, the federal government in the late 1960s funded reverse commute demonstration projects to link areas of high unemployment with job sites. Reverse commute bus services in several cities were provided by the then privately owned mass transit franchises. In an evaluation of the status of reverse commute demonstration projects, it was found that for all of the cities one in three riders obtained employment through the availability of reverse commute services (*2*). But ridership attrition rates were high and the mass transit industry did not find such service to be profitable. Many of the mass transit systems at that time were on the verge of bankruptcy. The conclusions of the study were visionary, since they suggested that nonconventional operations, such as jitneys, and new approaches to financial subsidies needed to be tested. These conclusions set the stage for the current interest in small, unconventional private-sector reverse commute services.

Several authors have noted that various private-sector arrangements have become established in commuter transportation markets, usually because there are significant financial benefits. One study showed that vanpool services are highly cost competitive with all types of private bus operation and much less expensive than public agency bus services (*3*). Vanpools are often 40 to 50 percent less expensive than transit agency commuter bus services in suburban areas.

Another study, which focused on the benefits of private-sector transit and paratransit systems in eight small urban and suburban areas, found that the private sector is able to operate services at a lower cost than public systems can (*4*). The study concluded that the private sector is more flexible and has more options for responding to problems such as fluctuations in demand. The use of private contractors in a competitive environment keeps costs down and provides controls on quality of service.

A study of the suburban mobility problems of elderly, handicapped, and low-income city residents in Louisiana found that there is potential for new private-sector public transportation services (*5*). The author recommended that more market-sensitive and user-friendly services such as paratransit or shared-ride taxis be substituted for regular transit in low-density areas and that city governments should facilitate the entry of the private sector into the commuter transportation market.

A recent study of private-sector reverse commute services in several cities concluded that government funding and employer financial assistance appear to be critical sources of support (*6*). Service operators found it necessary to provide some social services, such as training and child care, in addition to transportation, however. The author concluded that since transportation alone was not the solution, a coordinated effort among several agencies and organizations that deal with inner-city employment was required. He also concluded that there was perhaps no one model for successful reverse commute service.

It is apparent that private-sector commute services have become established because of public- and private-sector financial support and because such services can increase access to jobs at a cost lower than that of public mass transit. Yet other factors must be present for these services to thrive, particularly with little or no subsidy. Firms that are thriving and well managed strategically display the following characteristics:

- A lean management structure is close to operations and market information,
- All segments of the organization participate in the flow of communications,
- Management has appropriate strategies to increase revenues through targeted marketing and to manage costs, and
- Management continually monitors performance (*7*).

CASE STUDIES

Accel Transportation

Accel Transportation operates reverse commute service in the Chicago metropolitan area. Accel is a for-profit subsidiary of the LeClaire Courts Service Corporation, a public housing resident management corporation. Accel also has organizational links to the Clarence Darrow Center, another subsidiary of LeClaire Courts, which offers job and life experience training for public housing residents.

Accel consists of the general manager, an operations manager, a mechanic, dispatchers, and drivers. Although they have no previous background in transportation, the members of the organization do have experience with business and strong links to social services through the Darrow Center. Accel's management and staff are young, enthusiastic individuals who have bought into the organization. They hold frequent meetings, and the management style is open.

Accel came into existence at the urging of the National Center for Neighborhood Enterprise, a national organization promoting private-sector solutions to social and economic problems in urban areas. Accel applied for and obtained an ESP grant of $90,000 for planning purposes. Other grants have been obtained through the Regional Transportation Authority (RTA) for local demonstration. The Public/Private Transportation Network (PPTN), an FTA-sponsored technical assistance program, provided some short-term technical assistance to Accel during the initial stages of planning and operation.

Since there were no market research skills in-house, a class at Northwestern University conducted a market study for Accel. DuPage County, a suburban county west of Chicago, was selected as a promising market area for reverse commute services because of the rapid economic growth occurring there. Through discussions with the DuPage County Chamber of Commerce it became apparent that employers had particular problems obtaining entry-level labor.

Accel encountered no serious competition in the Chicago–to–DuPage County market. PACE, the suburban bus system in the metropolitan area, provided very little service in the county. The county had some small private-sector fixed-route operators and illegal taxis, but it remained inaccessible to many city residents. Other reverse commute services operated in the northern suburbs of Chicago.

Accel did not face any serious regulatory hurdles, either, since it would act not as a common carrier but as a contract carrier for employers. Insurance was a major financial obstacle, however. The state perceived Accel as a taxi or limousine service for insurance purposes and required $1 million liability coverage, costing $6,000/van.

Accel first marketed its services to employers in all of DuPage County but has since concentrated its marketing to specific service areas. Accel promoted its services to the private industry council and developers, at Chamber of Commerce meetings and through membership in suburban transportation management associations. Accel's services were not promoted to retailing firms because of the generally low wages and high employee turnover in that industry. Accel encountered reluctance among some employers to hire LeClaire Courts residents but was able to convince employers that its services would reduce costs for employee recruitment and training and relieve transportation obstacles.

Accel originally marketed its services to its own client base at LeClaire Courts through surveys of unemployed residents. The response to Accel's marketing was enthusiastic, since participating residents would have subsidized transportation to employment and access to day care programs, after-school programs, family counseling, and health services through the Darrow Center. But during the first year of operation about half of the riders were people who already worked in DuPage County but had inconvenient means of transportation. Promotion of the service to the unemployed has been done through newspapers and word of mouth.

Accel developed a relationship with the Chicago Institute for Economic Development, which would screen job seekers for employment by area employers. Accel would then provide the transportation service and design specialized programs for employers, including government-funded wage subsidies and employer tax credits, and consultation regarding work place conflict and employee work habits.

Contracts have been established with hotels, nursing homes, a food assembly plant, maintenance company, and an automobile repair franchise. The criteria for establishing contracts for service with employers were and continue to be

- Employer willingness to hire LeClaire Courts residents;
- Employer location in area being served;
- Employee wages of $5.25/hr, or more, plus benefits;
- Van trip revenues that cover costs; and
- Available vehicle capacity.

Accel has developed a routing and scheduling plan using maps, data on employer location and travel times, and fares based on distance. Times of operation are based on the shifts worked by the employees. Accel van services depart from the headquarters and other sites on the south and southwest sides of the city within easy access to major expressways. Accel operates from 6:00 a.m. to 12:00 a.m., 7 days a week.

Vehicles were maintained at first through a maintenance contract with an automobile repair firm but now are maintained by an in-house mechanic. Personnel policies have been patterned after the policies of a similar service in another city. Drivers are hired from LeClaire Courts, but driver turnover has been high. Drivers are screened extensively before being hired, and vehicles are checked before each trip.

Accel continually measures its performance in two areas: ridership and financial condition. Accel has been able to cover its costs of operation through employer and employee fare payments, ESP grants, and grants from foundations. Accel's objective for ridership the first year of operation was to carry 90 persons. As specified in the 2-year ESP grant agreement with RTA, Accel's objective for the second year was to carry 120 passengers with 67 percent of operating costs covered by fares, employer payments, and non-RTA (foundation) grants and for the third year to carry 150 passengers with 87 percent of operating costs covered. After the third year Accel hopes to cover all costs without RTA funding.

Accel has been carrying more than 125 riders a day. The cost per participating employee is $4.00/day, which is shared equally by the employer and employee. For service beyond a 50-km (30-mi) radius, fees are negotiated with participating employers.

According to the general manager, the most difficult problem encountered by Accel has been the inexperience of the staff in transportation service. Much has been learned through trial and error. Accel has had difficulty maintaining ridership on certain routes and should have been more cautious about expanding service to new areas. Another problem has been the high turnover of drivers, but experience with screening and hiring of drivers has reduced that. An additional problem has been determining the appropriate mix of vehicles.

The general manager describd the ESP program as appropriately funding new reverse commute services, but technical assistance is too casual. Reactive technical assistance, as supplied by PPTN, is not sufficient, since many operators do not have the knowledge to ask the appropriate questions. Minorities have been encouraged to initiate new services through the ESP program, but historically they have not been in management positions with transportation services. Thus, according to the general manager, long-term training in marketing and market research and in providing transportation service should be part of the program.

Accessible Services, Inc.

Accessible Services, Inc. (ASI), a transportation brokerage, marketing, consulting, and management services firm, operates the Job Relay System, a reverse commute service in the Philadelphia metropolitan area. ASI contracts van services from various carriers to provide reverse commute service. Thus, ASI has avoided major capital investments as a way to remain flexible in a potentially competitive environment.

The management structure of ASI consists of the president, an operations manager, and schedulers. The president of ASI and family members have operated social service transportation in the area for many years. For an hour a week, a part-time sales representative markets the service to business park employers and developers. The president of ASI is a results-oriented entrepreneur and has a keen appreciation of marketing and promotion and an impatience with institutional obstacles. Because ASI is a small, close-knit family operation, there appears to be good communication.

ASI established the Job Relay System after some developers of suburban office parks had expressed interest in reverse commute services to their locations. ASI contacted business, government, and social service organizations and learned that such a service would be well received. ASI then contacted a professor at the University of Pennsylvania, who assisted in obtaining one of the first ESP grants. The university acted as the public-sector sponsor and funding conduit for the Job Relay System. With the professor's assistance ASI researched the market and evaluated the feasibility of providing service.

The market research showed that several suburban counties, particularly the King of Prussia area of Montgomery County, west of Philadelphia, were experiencing rapid growth in suburban office and business park development. These parks are in dispersed campus-like settings located near expressways but not well served by the Southeastern Pennsylvania Transit Authority (SEPTA). ASI planned to serve only those parks that could be reached within a 45-min commute time from public housing sites in west Philadelphia; it was estimated that the service would be able to capture 1.5 to 2.0 percent of total park employment.

Other private-sector and inner-city groups competed in this market and elsewhere in the metropolitan area, but it was believed that the area could support several reverse commute services.

ASI encountered no state regulatory problems because the reverse commute service would not compete with SEPTA routes and would be not a common carrier but a brokerage service contracting with carriers. SEPTA did have some initial objections to the service, however. State insurance regulations required carriers to have $1 million to $2 million of liability insurance, a cost that ASI would face indirectly through its contracts with carriers.

ASI found that employers would not subsidize a commute service unless employee recruitment was also included, but some employers were reluctant to hire inner-city minorities and preferred suburban students and housewives. ASI was able to show employers that the service would reduce recruiting and other employee costs significantly. The president of ASI met with personnel managers and heads of firms to sell the service on the basis of financial and tax benefits.

ASI then contacted the Urban Affairs Partnership, the civic and social service arm of the Philadelphia business community, for assistance in developing the links to employment, training, and social services organizations that could supply trained labor. The Urban Affairs Partnership had a program, the Community Occupational Readiness and Preparedness Program (CORPP), that would screen and train individuals, as well as contract with other recruiting, referral, and training organizations. CORPP would thus match labor with appropriate jobs.

In practice CORPP was not prompt in supplying recruits that had been certified by the state Office of Employment and Training. For employers to receive $2,400 in tax credits under the federal Targeted Jobs Tax Credit Program, all new employees had to be certified after being offered a job but before they started work. CORPP and the subcontractor organizations could not provide a steady flow of trained recruits, which meant that ASI could not deliver new employees to suburban employers and would not be paid for transportation service.

ASI then developed its own network of churches, resident-management groups, and 18 to 20 other community-based organizations to recruit and train employees. These organizations are informal grass-roots groups with an abundant clientele of low-wage and unemployed people. ASI still had problems with this new network in obtaining certified recruits in sufficient quantities and in time for employers' needs, but this hands-on approach, though requiring more time and effort, was an improvement.

ASI has contracted with hotels and industrial employers in various business parks. Developers of such parks saw the service as a real advantage in marketing their buildings to lessees and buyers of space. ASI's criteria for establishing contracts with employers for service were

- No employers, such as retail firms, paying less than about $5.50/hr;
- No sweat shops, such as sewing contractors;
- No racist employers;
- No fly-by-night employers; and
- No service outside established service areas.

ASI staff schedules service on a demand-responsive basis (since many riders work variable shifts), monitors carrier operations, inspects carrier vehicles, and responds to police complaints of carriers with whom ASI does business. As a brokerage service, ASI has no direct control over the drivers except through the contract provisions with carriers and thus cannot respond to service complaints as quickly as a carrier can. Contract provisions are used to discipline carriers that do not meet service requirements.

ASI keeps track of financial performance through conventional accounting methods. ASI has charged employers $6.00 and riders $4.00 for a door-to-door round trip with the employee contribution made through payroll deduction. ASI has been able to earn a profit when there are seven riders per van at $5.00/trip, because carriers have charged $25.00/hr per van for an average time of use of 1.5 hr. ASI receives no subsidy except from employers and the ESP seed money.

ASI's ridership is approximately 150 but it has fluctuated greatly. Many riders have dropped out of the service because of promotion to higher-paying jobs and use of automobiles, day care problems, or incompatibility with the work environment. ASI must add from 15 to 30 new riders a week to maintain a stable ridership base.

According to the president of ASI, ESP is a good program that provided much-needed seed money, but there are too many restrictions. One cannot use grant money for marketing materials, only for planning and coordinating the start of operations. ESP grants should not pay after the fact, because many grantees have cash flow problems and cannot wait for reimbursement. Many grants are given not to established providers but to community groups without transportation experience.

Central Transit System

Central Transit System provides reverse commute service in the Orlando metropolitan area. Central Transit has consisted of the president, an assistant, a driver, and on-call, part-time drivers. Communication is facilitated by the firm's small size and informal management style. Central Transit has developed personnel policies regarding compensation and benefits and has instituted programs on training, safety, and drug testing that are being provided by outside vendors. Enthusiasm, desire for results, and willingness to take risks characterize the president's entrepreneurship.

The president of Central Transit had no prior experience in transportation but did have a previous business that was listed in the local telephone company directory under "Vanpools" by mistake, and employers called and expressed interest in an employee shuttle service. Because of this apparent demand for commute service and the lack of success in the previous business, the president contacted various transportation agencies and attended an FTA conference on ESP grants.

Central Transit researched the Orlando market through review of various sources of demographic data and the want ads, mapped the low-income neighborhoods in the city, and targeted the neighborhoods that were not extensively served by mass transit and the lodging industry serving the various theme parks in Osceola County, south of Orlando. State economic and insurance regulatory provisions were not major barriers to entry.

Central Transit contacted the various job placement agencies in the area as well as the local private industry council, but it found these organizations to be uncooperative and too bureaucratic, essentially unwilling to work with a middleman. Central Transit submitted a proposal to FTA for an ESP grant through Tri-County Transit, the public transit system in the Orlando area, and contacted various neighborhood organizations to market services to the labor force. Through these organizations flyers were distributed that listed available jobs and Central Transit's phone number. Job seekers would call Central Transit and would be screened over the telephone. Central Transit then contacted employers to set up meetings at which the service product was described. Employers were not reluctant to hire minorities, since most were in great need of housekeepers, jobs that have been held historically by minorities. Central Transit dealt only with those employers paying at least $5.00/hr.

The first contract for service was established with the Marriott Hotel. Marriott agreed to pay $5.50/employee per round-trip, and each employee paid $4.00 round-trip. Round-trip distance is approximately 100 km (60 mi). Other hotels have since established contracts for service.

Central Transit leased the first vehicle, a six-passenger van, for 1 month from a vehicle leasing firm. The lease contained provisions for insuring and maintaining vehicles. When the Marriott Hotel paid for the first month's employee transportation, Central Transit was able to continue leasing the vehicle monthly for the first 3 months, until revenues increased sufficiently for long-term leasing. Thus, the vehicle was obtained through very little up-front capital and a positive cash flow.

Central Transit's president operated the vehicle for the first 7 months starting at 6:30 a.m. and ending at 8:30 p.m., 7 days a week; then a driver was hired. Turnover has been high, but there has also been an abundance of available drivers. Central Transit screens prospective drivers extensively and releases them quickly when they do not meet expectations.

Central Transit has concluded that matching low-wage labor to employers has been too burdensome because of the high turnover in jobs and ridership. Targeting low-income areas of the city for labor has not worked well, since many single parents on welfare do not work long term for $5.00/hr.

As a result of the high rider turnover, Central Transit has made an arrangement with Tri-County Transit to operate a fixed-route service (Employee Transportation Management Program) in Osceola County that would be supported by employers, government, and riders. Tri-County Transit does not serve Osceola County and would in effect contract out such service to Central Transit. State and federal programs for transporting disadvantaged persons would provide funding toward this service.

To manage this new program Central Transit has opened more offices and hired a manager and supervisor of operations at each one. In addition several more vehicles have been leased, including paratransit vehicles. Central Transit has also moved into the transportation management arena by submitting proposals for local specialized services.

According to the president of Central Transit, the first obstacle to service was insufficient capital, but a flexible vehicle lease arrangement overcame it. A second obstacle of driver unreliability and turnover has been lessened by driver screening and an abundance of available drivers. A third obstacle was the absence of support from government and nonprofit employment and training organizations. On the other hand, active local government support for the planned fixed-route service has been a boon to continued survival and future growth.

According to the president, most operators do not have money for marketing, financial studies, and advice when initiating service. The ESP program has provided the needed financial support for operators, but operators without transportation and marketing experience often need long-term advice and assistance. The short-term technical assistance from PPTN requires enough knowledge to ask specific questions. Since many do not have this knowledge, a training and advisory component should be available.

Analysis of Cases

The case studies of reverse commute service have revealed factors that are critical to successful private-sector operation with little or no subsidy. All three reverse commute services are characterized by lean management structures directly involved in marketing and operations. They have as their top managers individuals who are self-confident and oriented toward results and marketing.

Management strategies heavily emphasize market research, promotion, minimal capital investments, and maximum flexibility. According to management at all three services, communication is frequent and unencumbered because of small organizational size and informal management style. The managers monitor financial performance and ridership, information that influences the marketing to employers and riders.

Market research, marketing, and sufficient financial resources are critical to the initial stages of planning and operation, but accurate and detailed market research information was not readily available to the companies. There was also some difficulty obtaining ESP grants at the right time for the needed purpose.

All of the commute services have established contracts with major employers not only for employee transportation but also for recruiting employees. As a result, they have had to form relationships with social service, employment, training, and recruitment organizations (government and nonprofit). Two of the commute services encountered reluctance among some employers to hire minorities. Yet inner-city minorities have been hired, particularly for those occupations that historically have been held by minorities.

The commute services have dealt primarily with manufacturing, distribution, some service, and lodging firms, avoiding retail firms and restaurants because of the low wages and high turnover among employees. Employers have subsidized employee trips when shown that labor access, recruitment, advertising, and training costs and tax savings can result.

Sufficient ridership and recruitment levels are critical to maintaining successful operation. Two of the commute services have had difficulty establishing links to employment, training, and recruitment organizations. Matching employment opportunities with available labor in sufficient quantities to maintain ridership has been difficult. The organization with historic ties to social service, employment, and training organizations has had more success.

Ridership turnover among low-wage, entry-level workers has been a major problem for the commute services. Many employees stop using a service because of promotions with higher wages and use of automobiles, insufficient financial incentive to work long term, or incompatibility with the work environment. Driver turnover has been the biggest operations problem facing service providers but has been mitigated over time as labor screening has improved.

The two commute services without previous transportation experience learned to operate through trial and error and expressed a desire for a long-term training component. In their opinion, short-term technical assistance, such as provided by PPTN, was not sufficient.

CONCLUSIONS

Private-sector reverse commute services have become established because of public- and private-sector financial support and because they can increase access to jobs at a cost lower than that of public mass transit. However, other factors are critical to success. One should not make sweeping generalities from three cases, and further research is needed, but certain common factors are apparent among the three.

The factors of successful private-sector reverse commute services are

- A lean management structure with dynamic entrepreneurship and communication;
- Strategies emphasizing financial flexibility and marketing (market research to identify promising market niches and promotion that emphasizes cost savings to employers);
- Establishment of contracts with employers for subsidized transportation and matching of jobs with labor;
- Close relationships with employment, training, and recruitment organizations;
- Comprehensive screening of commute service employees; and
- Monitoring of performance.

As a means to promote such services, FTA should implement a training and long-term technical assistance component to complement the financial assistance of ESP.

ACKNOWLEDGMENT

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Funding Methods for Urban Railroad Construction and Improvements in Japan

DEREK DYLAN BELL

Research was conducted to inform transportation professionals worldwide about passenger railroad funding methods being practiced in Japan. The data presented were obtained largely through a literature survey and discussions with transport-related officials in Tokyo. The most common forms of rail transit funding were various types of loans, bonds, subsidies, and beneficiary charges. Other methods included public investments, fare increases, a national railroad improvement fund, and internal cross subsidization. Japan, unlike the United States, does not contribute any portion of its gas tax revenues to transit. As a result, cities in the United States may want to look in more detail at how Japan manages to construct and improve urban rail transit without relying on gas tax revenues. The most complete and up-to-date information on Japan's passenger railroad funding methods available in English is provided.

Before rushing into a detailed presentation about how railroad construction is funded in Japan, it is necessary to give the reader some knowledge about the important historical differences between Japan and the United States in the development of transportation and how these differences have shaped the current transportation environments in these two countries, particularly in Japan.

Urbanization trends in Japan and the United States, measured as the percentage of population living in urban areas, are illustrated in Figure 1. It is evident that the U.S. experience was one of steady growth in the cities whereas that of Japan was extremely rapid in recent decades, largely the result of urban migration in response to massive reconstruction efforts after World War II and Japan's desire to reach equal economic status with Western powers.

Figure 2 shows how the automobile developed in Japan and the United States. Considering that in 1970 both countries had the same level of urbanization yet very different levels of automobile ownership, as shown, one can assume that the late introduction of the automobile to Japan and the country's rapid urbanization combined with the government's long-standing policy of a rail-centered transportation system hindered automobile (and road) development and served to make rail transportation very attractive in this densely populated country.

Domestic transportation mode shares in terms of passenger kilometers per capita in Japan and the United States are shown in Figure 3. Clearly, travel by rail and bus is common in Japan—34.6 and 10.2 percent, respectively—combining for nearly 45 percent of total mode share versus less than 2 percent in the United States. Japan's pie is smaller in area than that of the United States because the countries are proportional to one another in terms of passenger kilometers per capita. Therefore, in Japan people tend to travel shorter distances and less frequently by motorized transportation than in the United States. This deduction is reasonable since Japan is only 90 percent the size of California in terms of land area and has a population equal to one-half that of the United States, or more than four times that of California, indicating that mobility is indeed lower in Japan than in the United States.

Figure 4 illustrates how difficult it has been in Japan to reduce overcrowding on trains during the morning rush hour by increasing train capacity; the figure presents this trend for Japan's 15 major private railroads, concentrated in the Tokyo, Osaka, and Nagoya regions. Although train capacity has tripled since 1960, the average rush-hour overcrowding rate has only decreased from 230 to 180 percent capacity. In the case of Japan Railways (JR), capacity has increased by more than 250 percent since 1960, but the average rush-hour overcrowding rate has only decreased from 270 to 210 percent capacity (*1*).

Overcrowding is such a common situation that the East Japan Railway Company (JR East) has published an illustration portraying the ways in which overcrowding rates relate to rider comfort and discomfort. Once overcrowding reaches 200 percent capacity, the description states, "bodies touch firmly, pressure felt, possible to read a small book or magazine," and at 250 percent, "everyone leans in unison as the train moves, cannot move body or even hands" (*2*,p.9). Some trains in Tokyo are now equipped with folding seats that are to be used only during off-peak periods (i.e., if everyone stands, the practical capacity of the train is increased). Another example of overcrowding in Tokyo's Shinjuku Station, which processes about 2.8 million passengers per weekday.

The foregoing discussion and figures demonstrate the seriousness of the rush-hour overcrowding problem on railroads in Japan and consequently the reason that transportation authorities in Japan believe that they need to continually increase rail capacity and make large-scale railroad improvements. The following section explains the many ways in which railroad construction and improvement funds can be obtained in Japan.

INTRODUCTION TO RAILROAD CAPITAL FUNDING METHODS IN JAPAN

Railroad construction and improvements are very expensive projects that require a great deal of capital investment. Because of the large amount of capital involved and the long-

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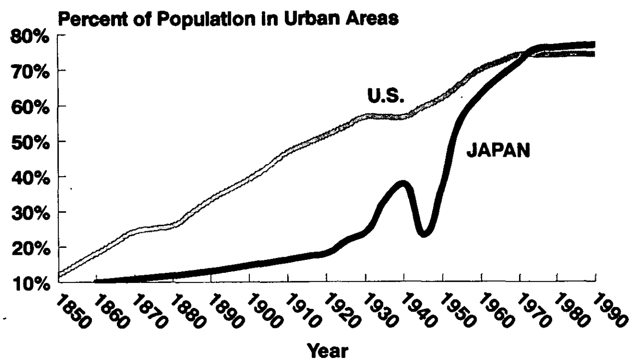

FIGURE 1 Urbanization trends in Japan and United States.

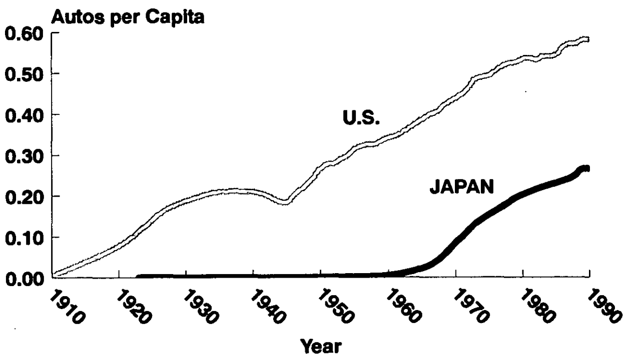

FIGURE 2 Automobile ownership trends in Japan and United States.

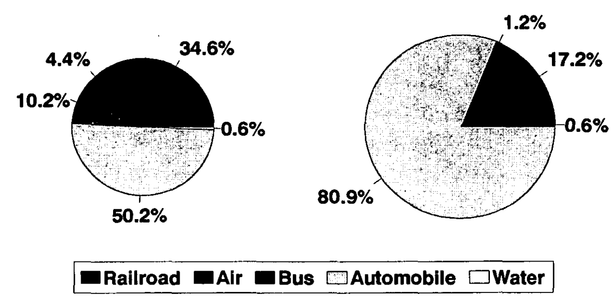

FIGURE 3 1990 domestic transportage mode shares (percentage of passenger kilometers per capita): *left*, Japan; *right*, United States.

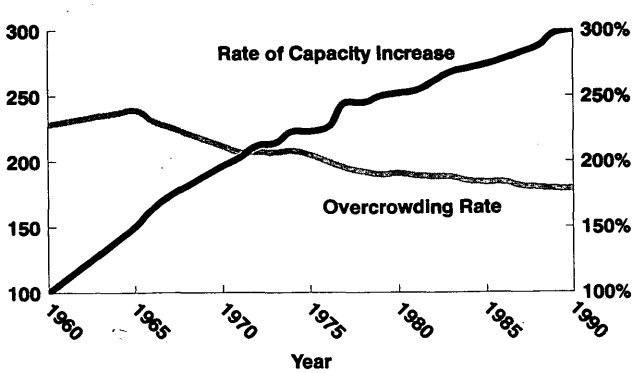

FIGURE 4 Trends since 1960 for rate of capacity increase (in terms of passengers; values normalized to 1960 level of 100) and average passenger overcrowding rate during rush hour in Japan, major private railroads.

term nature of such investments, usually only government bodies or very large and financially secure institutions or companies can afford it. Raising sufficient funds for railroad projects is often a difficult process that brings up issues such as public- versus private-sector responsibilities, burdens, and perceived benefits.

The national government's role in providing capital assistance for railroads is based on the following fundamental policies:

1. To ensure the improvement of transportation facilities that benefit the public,
2. To induce development by providing assistance to local governments through improved transportation facilities,
3. To assist local governments financially that are unable to pay fully for needed transportation improvements,
4. To provide a standardized transportation system nationwide,
5. To provide local governments with incentives to construct and improve transportation facilities, and
6. To redistribute income equally among all local governments nationwide.

Rail transit planners in large cities such as Tokyo and Osaka believe that further investment in railroad improvements is needed to relieve serious overcrowding on existing trains and road congestion. In medium-sized cities such as Sapporo and Fukuoka, which still have populations of more than 1 million each, the stated purpose of railway investment is to influence city structure and relieve road congestion.

However, the capital costs of rail improvements in Japan are immense. Land acquisition costs are one of the biggest expenses for urban rail transit. Underground space, although cheaper, still costs 20 to 50 percent of the surface land price (*3*,p.41). According to the Japan Real Estate Institute, residential land in the six major cities (Tokyo, Osaka, Nagoya, Sendai, Sapporo, and Fukuoka) increased in real value by almost 39 times between 1955 and 1990. From 1980 to 1990, the real value tripled (*4*,p.86). Since 1990, however, it has declined by 20 to 30 percent.

DETAILS OF RAILROAD CAPITAL FUNDING METHODS IN JAPAN

The following discussion covers 20 ways in which railroad companies can try to obtain capital funds in Japan (*5*). A summary of these methods is given in Table 1. Of interest to many transportation professionals in the United States would be two items not included in this list: gas tax revenues and toll road revenues. Neither of these revenue sources goes toward funding transit in Japan; they are mainly dedicated to construction and improvements of expressways and other roadway infrastructure. This policy has significant implications, especially considering that Japan's current gas tax rate of ¥53.8/L (about $1.63/gal) is one of the highest in the world. Furthermore, the standard toll rate for regular passenger vehicles on Japan's high-speed expressways is ¥23/km ($0.30/mi); this is the same as a one-way drive from Oakland to Sacramento, Chicago to Milwaukee, or New York City to Hartford costing about $25 in tolls. Nevertheless, the

TABLE 1 Revenue Supply for City Railroad Improvements in Japan

Classification	System
Loans	NTT-B No-Interest Loan Japan Development Bank Low-Interest Loan Commercial City Bank Loan
Bonds	Local Bonds
Subsidies	Subway Construction Subsidy New Town Railroad Construction Subsidy Interest Payment Subsidy for Private Railroads Interest Payment Subsidy for Large City Railroads
Investments	Japan Development Bank Investment Local Public Group Investment
Beneficiary Charges	New Town Development Charges Special Assessment Districts Negotiated Exactions Land Readjustment Projects Fee from Station Petitioners Beneficiary Taxes Connector Fees
Transit User Fees	City Railroad Improvements Special Reserve Fund
Others	Railroad Improvement Fund Internal Cross-Subsidization

gas tax and toll rate enable rail transit to enjoy heavy patronage due, in part, to the correspondingly high out-of-pocket cost of operating an automobile. This is the opposite of the situation in the United States, where the pump price of gasoline is about one-third of that in Japan and Interstates are toll-free.

Loans

Most railroad construction and improvement funds are raised through loans. Because commercial bank loans tend to have relatively high interest rates, no-interest and low-interest loan systems have been established. However, because of a high degree of competition for funds, it is very difficult for railroad companies to obtain the special no- or low-interest loans. Essentially all private railroad companies will obtain commercial bank loans to pay for a significant portion of construction costs, and the major private railroads will receive relatively low interest rates anyway because of their financial stability.

NTT-B No-Interest Loan

The national government uses the Industry Investment Account (*Sangyō Tōshi Kaikei*) to provide capital investment loans for developing industries and promoting trade. Until 1953 this account was used to repay the United States for assistance provided after World War II. This account is now being used to help expand the nation's economy, improve people's living conditions, and clarify accounting procedures.

The source of the previous funds was the sale of Nippon Telephone and Telegram (NTT) stock in 1987 and 1988. The income from NTT stock sales was first used to pay for the redemption of government bonds. However, the capital gains from selling stock were often more than enough to cover the cash required for the bond redemption. The excess amount was then allocated to the Industrial Investment Account. Because of the decline in Japan's stock market and the plummeting of NTT stock over the past few years, the national government has allowed a transfer of some General Account funds to the Industry Investment Account.

The national government states that the funds from this account are used to provide no-interest loans to three types of business activities:

1. Type A: business loan. Funding is intended for public enterprises that can pay off the loan from business-generated income.
2. Type B: public assistance loan. The target here is for public enterprises that need general urgent improvements and those that help promote spatial development by potentially increasing a region's activities.
3. Type C: private investment loan. In this case, funds are spent on private investments. The income generated by these investments is then used to fund public enterprises that may contribute to increasing a region's activities through spatial development.

Of these three types, only the Type B loan has been used for investment in railroads. As a result, funding from the Industry Investment Account is commonly known as the NTT-B loan. The account is considered temporary and may last for only another 20 years. This no-interest NTT-B loan was provided to the Kansai High-Speed Railway Company in 1989. Currently, these loans are being used primarily to fund capital improvements of passenger terminal facilities.

Japan Development Bank Low-Interest Loan

The Japan Development Bank provides low-interest loans to railroad companies for construction that improves safety, capacity, or service. This has been used recently for large-scale improvements to existing Shinkansen (bullet train) lines. A summary of how this funding works is provided in Table 2.

Commercial Bank Loan

As a last resort, private railroads will obtain financing from a commercial bank. Because of tight government fiscal constraints and a high degree of competition for funds, borrowing from a commercial bank is not uncommon for railroad companies in Japan.

Local Bonds

Railroads with a high level of government involvement, such as subways and new town railroads, receive a large portion of their funding through bonds, depending on local financial law. These bonds are also used as a method of debt repayment on construction loans. Six types of bonds can be used:

1. Construction bonds,
2. Subway business special bonds,

TABLE 2 Japan Development Bank Low-Interest Loan Rates

Type of Construction	Funding Rate %	Interest Rate[d] %
Safety Improvements[a]	50	5.15
Capacity Increases[b]	50	5.15
Service Improvements[c]	35	5.50

[a]Includes elevated crossings, safer at-grade crossings, accident prevention, and track reinforcement.
[b]Includes rail into city center, new lines, double and quadruple tracking, adding more cars, extending platforms, car storage facilities, transformer substations, transfer station improvements, and multi-purpose passenger terminals for new lines in large cities.
[c]Includes air-conditioned cars, new stations, passenger facilities, and coordinated transportation facilities.
[d]As of November 2, 1992.

3. Capital burden relief bonds,
4. Loan bonds,
5. Tokyo Rapid Transit Authority transportation bonds, and
6. Japan Public Railroad Construction Corporation bonds.

Construction bonds are used specifically for obtaining construction funds for subways and new town railroads. The subway business special bonds are corporate bonds issued to assist with subway construction costs and construction loan interest payments. The capital burden relief bonds are issued to help relieve some of the costs associated with interest payments on subway business special bonds. Loan bonds are newly issued local bonds used to enable the redemption of corporate bonds (e.g., subway special business bonds) issued in the past. The Tokyo Rapid Transit Authority (TRTA) issues transportation bonds to raise up to 10 times the amount of its own capital needed for subway construction. The Japan Public Railroad Construction Corporation also issues bonds for railway construction, often for the six passenger JR companies (JR East, West, Central, Hokkaido, Shikoku, and Kyushu).

Subsidy System

Four types of government subsidy provide funding for new line construction and large-scale improvements: subway construction subsidies, new town railroad construction subsidies, interest payment subsidies for private railroads, and interest payment subsidies for large city rail lines.

Subway Construction Subsidy

The subway construction subsidy is used to cover 70 percent of the construction costs of subways. The national and local governments share these costs, paying 35 percent each. In 1991 a new formula was set, so that payments would be made over 5 years at 7 percent a year for each party. The previous year's formula called for payments over a period of 10 years with the following annual layout per party: 1, 2, 3, 4, 4, 5, 5, 4, 4, and 3 percent. However, the actual subsidy rate, determined after considering deductions for rolling stock expenses, interest on loans, and others, has fallen from 53.2 to 44.0 percent. In the past 10 years, the total layouts for this subway construction subsidy system have varied from ¥40 billion to ¥145 billion ($320 million to $1,160 million) per year, but because of Japan's recent economic decline the total amount of budgeted subsidies has not been realized in the past 2 years. To make matters worse, construction costs have continued to increase.

Officials at the Ministry of Transportation stated that there are two basic problems with this subway construction subsidy. First, these subsidies are provided to neither private nor public-private (third-sector) systems, which have been increasing in number and relative importance in meeting travel needs over the past few years. Second, the subsidy rate for subways in Tokyo and other cities is the same, although depending on the city, subway systems experience far different levels of patronage and, therefore, far different profit-making capabilities. Subways in Tokyo can easily earn enough fare revenues to cover operating expenses, but many subways in other cities cannot meet operating expenses without some form of operating subsidy from the local or national government. As a result, the national government is considering lowering the subsidy rate for Tokyo's subways and increasing it for systems in other cities. Such a change would be more in line with the government's stated policy regarding income redistribution.

New Town Railroad Construction Subsidy

The purpose of the new town railroad subsidy is to construct or improve rail lines to connect new towns in suburban areas of a big city to the city center. Generally, patronage is very low in the early stages because few houses are occupied in the new town. This system was established to decrease the capital burden on the new town rail system and is usually applied with value capture schemes mentioned later.

This system subsidizes 36 percent of the construction costs, with the national and local governments paying 18 percent each. It is allocated over 6 years at 3 percent per year per party. Total allocations over the past 10 years for this subsidy have varied from ¥216 million to ¥655 million ($1.7 million to $5.2 million) per year. Clearly, these funds are very small in comparison with the subway construction subsidies, largely because of the more expensive nature of subway construction.

Interest Payment Subsidy for Private Railroads

The aforementioned subway construction subsidies were established for TRTA and municipal subway construction, but private railroads were left out. Consequently, financially strapped private railroads after World War II only increased the number of cars per train and reduced headways to improve service. Only four new lines were constructed at that time.

The Japan Public Railroad Construction Corporation, which was initially established to construct rail for the former Japan National Railroads (JNR), allowed in 1972 an interest payment subsidy for private railroads that provided service between suburban area and city centers. According to this system, these private railroad companies as well as public railroads can receive assistance with interest payments on construction loans. The national and local governments each pay 50 percent of any interest expense that exceeds a 5 percent rate for a period of 25 years. New town lines receive such assistance for 15 years. However, this system is being used only for major lines in the three large cities of Japan (Tokyo, Osaka, and Nagoya). Local lines are unable to use such a system, and this is unfortunate.

Interest Payment Subsidy for Large City Railroads

The interest payment subsidy for large city railroads also provides assistance for construction loan interest payments over a rate of 5 percent, but the period is for 40 years. These long-term subsidies are granted only to large city railroads and main trunk lines that the Japan Public Railroad Construction Corporation constructs. The national government is fully responsible for this extended assistance. The combined layouts of the interest payment subsidies for both the private and large city railroads over the past 10 years have varied between ¥1.7 billion and ¥3.6 billion ($14 million and $29 million) per year. It is clear from these allocation figures that subway construction in Japan receives the bulk of government capital subsidies.

Investments

Private railroad companies often raise construction funds by selling stock, a form of "self-investment." This section discusses how national and local public bodies may invest in railroads.

Japan Development Bank

The Japan Development Bank occasionally invests in railroad companies that need to make urgent improvements to relieve severely overcrowded trains and congested bottlenecks. In 1990 the Japan Development Bank invested in the Kansai High-Speed Railway Company and the Hiroshima High-Speed Railway Company.

Local Public Group Investment

For construction of new municipal subway lines, local public bodies commonly invest some funds from their general accounts. The subway then uses this money as so-called self-capital. Local governments previously supplied a standard rate of 10 percent of the construction funds needed, but in 1990 they uniformly increased the rate to 20 percent.

As for third-sector railroads, the regional government and one or more companies join forces and establish their own company. JR East, the largest of the six JR group companies, believes that this is the best method for obtaining funds. JR East and the respective local government each contributes equal amounts, up to 50 percent of the total construction costs, and JR is not required to repay the local government for its share of the costs. Two completed third-sector projects are the Yamagata Shinkansen and the Narita Express. The New Joban Line and the Tokyo Bay Area Commuter Line are third-sector projects currently in the planning stages.

Beneficiary Charges

The development or improvement of public infrastructure commonly generates benefits not only to the users of the system but also to landowners and businesses in the surrounding areas. Assessing a beneficiary charge to these landowners and businesses is an accepted method of value capture practiced in Japan.

New Town Development Charges

The Ministry of Transportation, in consortium with the Ministry of Construction, has created a system whereby new town developers pay a construction fee and a site fee that go toward funding rail construction. This system is designed to improve private railroads that connect the new town to the city center, commonly located 30 to 40 km (18 to 25 mi) away. The railroad is constructed by a local public body and the Japan Public Railroad Construction Corporation. The housing developers and land improvement companies that own land where the private railroads are going to operate must sell the portion of land that the railroads need at a reasonable price and pay for half of the railway construction costs associated with their previously owned property.

Special Assessment Districts

When the Kobe municipal subway was extended to Suma new town, the local government set up administrative guidelines to obtain contributions from the new town developers for the railroads. The new town developers were required to give land to the railroads for free and pay for all of the railway construction costs. The fees were charged according to special assessment districts set up around the rail stations by the municipal government. The specific development charges were determined by a formula that mainly considered the distance of the development from the station. The developers were also expected to make large-scale developments in the areas around the stations. This system is unusual in that such a heavy burden was placed on the developers.

Negotiated Exaction

Negotiated exaction is different from the preceding two beneficiary charges in that a predetermined fee is not forced on the developers through laws or regulations. Developers and railroad companies work together in making an official and binding financial agreement that the developers should pay for a portion of the railroad operating, not construction, expenses. These negotiated exactions were performed between the Nose Railway Company and Nissei new town as well as between the Hokuso Development Railway Company and Chiba prefecture. In the case of Nose Railways, the developer also supplied half of the construction funds for an extension to Nissei new town and helped pay for an increase in the line's capacity.

Land Readjustment Project

Land readjustment projects are initiatives that try to improve the design of transportation and land use developments by rearranging existing structures where new rail systems are to be constructed. First, the project must be designated in a city plan or approved by a two-thirds vote of the landowners and renters in the area. Thereafter, the project can be carried out by a private developer or a public body such as a prefecture, municipality, or the Housing and Urban Development Corporation.

One good example of how this scheme can be successfully implemented is the Tokyu Den'en Toshi Line, also discussed later with respect to internal cross subsidization. The Tokyu Railway Corporation was able to solicit the voluntary participation of landowners to improve their properties through land use readjustment and public facility construction (e.g., roads, parks, sewers). These landowners were willing to have their properties rearranged because they believed that land values would increase with a new rail line.

According to Tokyu's system, Tokyu, which was the largest landowner along the proposed rail line, performed all readjustment projects for other landowners in return for small plots of "reserved" land expected to increase in value after the new rail line was in operation. With this system, Tokyu was able to secure the right of way necessary for the rail line and offset readjustment costs through resale or development profits of the reserved land (*6*,p.22). For an illustration of how this looks, see Figure 5. This entire process, from preparation of the initial development plan to the completed construction and opening of the last section of the rail line, took 30 years (1953–1984).

Station Petitioners

When there is no station near an existing section of rail, sometimes the nearby residents, developers, and local self-governing bodies will petition to the railroad company to build a new station. In this case, the petitioners often pay for the construction of this new station. There were many examples of this with the former JNR, and the method for charging the petitioners varied by case. Sometimes only the developers were burdened. Other times a new station fund was created by a local union that was then responsible for collecting money to meet construction expenses. Today there are very few cases of station petitioning.

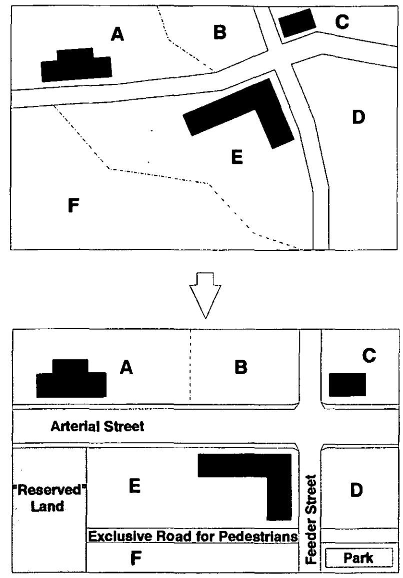

FIGURE 5 Land readjustment project: before (*top*) and after (*bottom*) execution.

Beneficiary Taxes

Local public bodies usually need to keep funds on hand to be able to grant subsidies for improvements to existing railways. This is normally done by levying beneficiary taxes, which can be easily administered for annual collection. The different types of beneficiary taxes used in Japan are corporate, enterprise establishment, real estate, and real property acquisition taxes. As business profits and land prices increase due, in part, to the railroad improvements, these taxes are used as a form of value capture. Beneficiary taxes have been set up in the cities of Sapporo, Sendai, Kitakyushu, and Fukuoka. In Sendai, half of the income from enterprise establishment taxes is channeled directly to a fund for railroad improvements.

Connector Fees

Many underground passageways connect subway stations and nearby buildings in Japan. Tokyo has numerous large-scale underground pedestrian corridor networks, which are very convenient during bad weather. Often one can go straight from a subway station to one's office or a major department store without stepping outdoors. Because the building owners benefit directly from these connectors, they are required to pay for part of the construction cost. The individual building owner's share of the cost is determined on a case-by-case basis through negotiations with subway officials.

Transit User Fees

In Japan, transit user fees, or fares, are established not only to cover some portion of operating expenses, but also sometimes to contribute to a fund specially created to help pay for future rail construction and improvements. This fund is called the City Railroad Improvements Special Reserve Fund and is used to pay for large-scale metropolitan railway improvements such as doubling existing double track. Passenger fares are a major source of revenue for this fund.

Initially, the railroad operator who would like to set up this fund should make a 10-year large-scale railroad improvement plan that explains specifically how it intends to increase capacity. Assuming that these improvements cost more than the current annual fare revenue minus operating costs, the operator needs to obtain authorization from the Ministry of Transportation to carry out the plan.

Once authorized, the operator can collect railroad improvement funds by increasing fare levels at a rate designated by the Ministry.

Investment Ratio	*Fare Increase (%)*
Under 2	3
2–3	4
3–4	5
Over 4	6

In this table, investment ratio is determined by dividing the city railroad total construction cost by the previous year's total fare revenue. It is evident that as the construction cost increases, the fare surcharge increases as well. The accumulated amount of this extra fare revenue is limited to 25 percent of the total construction cost called for in the plan. In annual financial statements and with respect to tax law, these newly generated funds are treated as a construction expense, are classified as a loss, and become tax exempt.

The authorized rail operator then must use the generated funds within 2 years to pay for construction costs associated with carrying out the improvements. In addition, the authorized operator is required to match these funds with some form of self-capital (e.g., loans, stock sales, investments) in paying for the improvements. The extra fare revenue should be used only to create this city railroad improvement fund, and according to law any unused amounts are to be returned to the users through fare reductions.

Clearly, many merits are associated with this system. Money can be raised before land purchases and construction efforts. The operators can claim the extra fare revenue as a monetary loss for future construction expenses. The amount of capital needed in the form of a construction loan is decreased, and therefore burdensome interest payments are reduced. Often, the new fare levels can be maintained as more improvements are approved and carried out. After several years, fares can be increased again to replenish the reserve fund and pay for further improvements. Thus, a cyclic pattern of continuous capital improvements can be established. For the past 2 years, this system has been widely used by private railway companies such as Tobu, Seibu, Keio Teito Electric, Odakyu Electric, and Tokyu Electric Express.

There are, however, two problems with this system as it stands today. First, JR, which still operates in a relatively restricted administrative and operational environment, is excluded from participating. Second, this method can only be used for construction that can be completed within 10 years.

Others

This section covers two other methods employed to obtain capital funding: the Railroad Improvement Fund and internal cross subsidization.

Railroad Improvement Fund

The main objective of the Railroad Improvement Fund (*Tetsudō Seibi Kikin*) is to promote improvements in city railroads, main trunk lines, and Shinkansen lines. It was also created to fund facility improvements that would improve railroad safety, plan for advancements in the area of passenger convenience, and increase operating efficiency.

The fund is created from corporate taxes, enterprise establishment taxes, developer charges, the General Account, and others. The contribution of beneficiary charges to this fund is based on local ordinances. Because railroad improvements are desperately needed in many urban areas, the Ministry of Transportation is investigating ways to maintain and increase the monetary flow into the Railway Improvement Fund.

Internal Cross Subsidization

When a company or public agency is both a developer and a railway owner it can very easily transfer development or other business profits to fund railway construction. There are three good examples of this: the Tokyu Railway Corporation, the Kobe municipal government (*6*), and JR East.

Besides its railway business, the Tokyu Railway Corporation owns and operates buses and has a real estate department that develops department stores, supermarkets, shopping plazas, hotels, and recreational facilities. Profits from the real estate business were used as working capital to put these other businesses in the newly developed areas (Den'en cities) where the rail line (Tokyu Den'en Toshi Line) was being constructed. Tokyu made these areas very attractive places to live, and consequently people moved there. By using profits from its real estate business and from the newly placed Den'en businesses, Tokyu made improvements to the rail line and it subsequently received patronage.

It is important to note that the real estate business of the Tokyu Railway Corporation is separate from that of Tokyu Realty, its affiliated company. Tokyu Realty specializes in real estate, and its annual revenues are about 50 times those of the Tokyu Railway Corporation's real estate department. These two companies are allowed to hold significant numbers of shares of each other's stock, but because of antitrust laws, it is illegal for one of them to transfer (cross-subsidize) funds to the other.

This system was also easy to implement for the Kobe municipal government, mentioned earlier with respect to residential developer fees. The Kobe City Development Bureau was the main developer of new towns in the area, and the Kobe City Transportation Bureau was responsible for regional rail operations. The municipality simply transferred profits from the City Development Bureau to the city's general fund, which was then used to cover some of the initial investment costs and operation losses of the railway.

JR East even has the capability to cross subsidize profits from its other businesses. JR East owns and operates shopping centers, hotels, information services, kiosks, restaurants, sports and leisure facilities, travel services, advertising agencies, and so on. Such examples are rare in the United States (mainly due to legal restrictions) but commonplace in Japan. JR East plans to expand in areas of finance, real estate, resort development, and leasing. By 2000, JR East expects these related businesses to make up 50 percent of total company revenues and railway operations to contribute the other 50 percent.

CONCLUSIONS

Loans, bonds, and government subsidies contribute a large portion of urban rail transit funding in Japan, but many other funding methods are available. Some of the more interesting ones include a special fund set up through fare increases, a variety of beneficiary charges, and a rail provider's ability to cross subsidize internally. These latter strategies take the burden of funding rail projects off the government and place more responsibility with the railroad companies and appropriate landowners. U.S. cities wanting to build new or improve existing rail lines may find it useful to take a look at Japan's experience with funding passenger railroads, especially since gas tax and toll road revenues are not a part of the equation.

Because raising fares on rail lines in the United States may have adverse impacts on ridership, a phenomenon not observed in Japan because alternative modes are relatively high priced, adopting some of the beneficiary charges practiced in Japan may provide a better financial climate for constructing urban passenger railroads in the United States. But as long as the alternative modes are perceived by potential users as superior (e.g., cheaper, faster, more convenient), U.S. rail systems in general will continue to suffer low patronage and the associated financial losses.

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Transit Privatization in Denver: Experience in the Second Year

ROBERT L. PESKIN, SUBHASH R. MUNDLE, AND P. K. VARMA

The performance of the Denver Regional Transportation District (RTD) and its contractors during the second year of privatization, July 1, 1990, through June 30, 1991, is described. Cost, profitability, safety, quality of service, and contractor compliance experience is updated from previously published results from the first year. In addition, new findings are discussed regarding the source of savings, maintenance inspections, and bus operator wages and turnover. On the basis of actual cost history, a short-term incremental analysis demonstrated a savings of $2.5 million, or 12.5 percent. On a long-term fully allocated basis, the savings were estimated at 25.8 percent without depreciation and 31.0 percent with depreciation. The contractors' profitability was approximately 2.4 percent, measured as revenues over expenses. In terms of bodily injury and property damage accidents, on-time performance, maintenance reliability, and complaints and commendations, there was no consistent difference between the performance of RTD and that of the contractors. More than half of the savings in actual operating costs was due to the lower wages and fringe benefits paid by the contractors. Whereas the contractors experienced higher bus operator turnover as a result, there was no indication that safety and quality of service were affected. The contractors' rate of operator terminations for cause and resignation was similar to that of RTD. The contractors' lean maintenance staffing may be the cause of observed instances of maintenance deficiencies.

The performance of privatized transit services of the Denver Regional Transportation District (RTD) is documented for the period July 1, 1990, through June 30, 1991. It is based on a study prepared in response to a request by the State of Colorado Highway Legislation Review Committee (*1*).

Privatized transit services in the Denver region were significantly expanded in response to the provisions of Colorado Revised Statutes 32-9-119.5, as amended, specifically the provisions of Senate Bill 164 of 1988 and Senate Bill 8 of 1990 (hereinafter referred to as SB 164). SB 164 required that RTD contract at least 20 percent of its service to qualified private businesses in negotiated contracts.

This paper follows up portions of prior papers by Peskin et al. (*2,3*). It updates the cost, safety, and quality of service experience and the contractor compliance experience. The paper also addresses important new findings regarding the source of cost savings, vehicle maintenance, and operator wages and turnover.

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COMPARISON OF RTD's NET IN-HOUSE COSTS OF PROVIDING TRANSIT SERVICE ON PRIVATIZED ROUTES WITH NET COST TO RTD OF PRIVATIZATION

Basis of Cost Comparison

The cost comparison involved two alternative approaches in order to provide a realistic range in which the eventual fiscal results of privatization will probably reside. This was accomplished through the estimation of incremental and fully allocated costs.

The purpose of incremental costing analysis was to identify near-term "bottom-line" effects of different management decisions, each resulting in alternative revenue and cost flows. This approach was addressed in the analysis in two ways:

- Administrative costs: the incremental analysis computed the actual reductions in such costs during the analysis period. The fully allocated analysis (described later) implied a theoretical reduction in administrative costs proportionate to the quantity of service privatized.
- Depreciation costs: the incremental analysis does not address the sunk capital-related costs for depreciation.

Short-term incremental cost analyses may, therefore, provide an achievable lower boundary of projected financial impacts based on actual cost results.

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

- RTD's administrative costs were influenced more by board and federal policy, organizational structure, and fixed capital plant than by service levels. The fully allocated cost analysis assumes that such costs are directly related to the quantity of service provided and thus projects pro rata savings. The likelihood of this occurrence was remote. Savings in administrative functions were dependent more on management initiatives and board policy than on service levels.
- Long-term financial forecasts, and the fully allocated cost projections on which they were based, imply that RTD had the ability to modify the infrastructure that was assembled to operate the preprivatized service. This included a large administrative staff and large discrete fixed assets (e.g., garages) that may have been less efficiently deployed as a result of reducing directly operated service.

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

Cost Allocation Model

A state-of-the-art cost allocation model, which addressed differences in labor productivity and unit cost associated with the different types of service that RTD operated, was updated for this study. The model was calibrated on the basis of actual costs for the analysis period. It distinguished labor productivity and other unit cost factors for peak and off-peak service, different types of buses, and different RTD bus garages. It was thus possible to apply the model at the route level.

The cost allocation model did not include the costs of "retained functions," which included various administrative and operations functions that RTD continued to provide regardless of whether it operated the routes to be privatized. Many of these functions represented systemwide responsibilities that could not have been economically privatized or that RTD was specifically mandated to perform.

Retained functions included the following:

- Board office
- General manager's office
  - –General administration
  - –Public relations
  - –Intergovernmental relations
- Legal counsel
  - –Litigation, real estate
  - –Property management
  - –Risk management (accident reporting system)
  - –Liability insurance (shared equipment and facilities)
- Materials management (privatization contract administrator)
- Communications (entire department)
- Customer service and scheduling (entire department)
- Finance
  - –Public relations
  - –Revenue collection
  - –Controller, administration
  - –Financial reporting
  - –Ridership reporting
  - –Commercial advertising
  - –Capital planning, budget, grants administration
  - –Information systems: systems applications and associated manpower related to traffic checking, scheduling, customer communications, maintenance reporting, facilities maintenance, warranty, accident reporting, bus stop inventory, farebox maintenance, bus assignment, farebox revenue reporting, general ledger (portion), budget (portion), financial management system (portion), personal computers (portion)
- Administration
  - –Print production management
  - –Janitorial services (mall stations)
  - –Planning and development: system planning
- Bus operations
  - –Security (stations and garages)
  - –Administration (manager of contract services, leases for park-and-ride lots)
  - –Operations analysis, service monitoring (maintenance reporting system)
  - –Transportation services dispatchers, street supervisors (portion), mall supervision
  - –Facilities maintenance: public and transfer (including the maintenance of 10,000 bus stops, 415 bus shelters, 45 park-and-ride lots, the Market Street and Civic Center stations and Boulder Transit Center, and the 16th Street Mall)
  - –Maintenance services: new warranty and quality control (routine inspection of contractors' buses)
  - –Vehicle maintenance (radio mechanics, supervisors, and parts)
  - –Support vehicle maintenance (snow removing and landscaping vehicles and equipment used at park-and-ride lots; some street supervisors' cars).

The retained functions represented $12.9 million, or approximately 12.4 percent of actual expenses (omitting depreciation and excluded functions, explained later). In addition, the cost allocation analysis did not address various capital project-related and one-time-only expenses. Such excluded functions represented $11.8 million, or 11.39 percent of actual expenses (omitting depreciation).

Results of Cost Analysis

Figure 1 summarizes the results of the incremental cost analysis. Actual savings resulting from privatization were estimated at $2.5 million, or 12.5 percent of RTD's in-house cost. This is lower than previously published projections of incremental savings because this projection includes half of calendar year 1990 (previously projected to operate at an incremental cost of 1.8 percent) and half of calendar year 1991 (previously projected at an incremental savings of 18.8 percent), and because RTD's actual costs were lower than projected, due partly to lower inflation.

Figures 2 and 3 show the results of the fully allocated cost analysis: a savings of $5.1 million (or 25.8 percent) without depreciation and of $7.5 million (or 31.0 percent) with depreciation. These values are higher than previously published

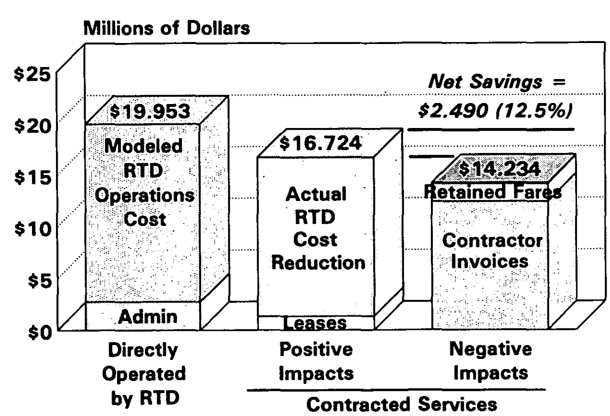

FIGURE 1 Incremental cost comparison (without capital costs).

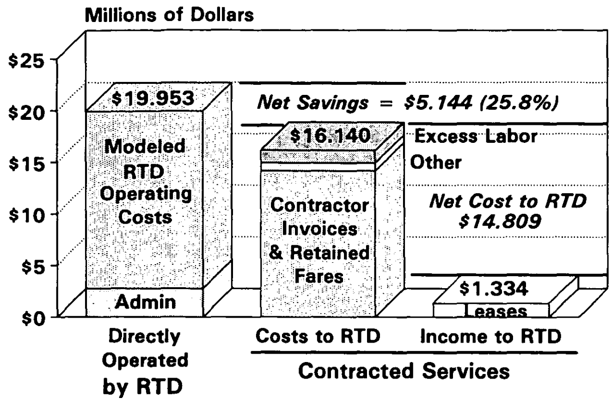

FIGURE 2 Fully allocated cost comparison (without capital costs).

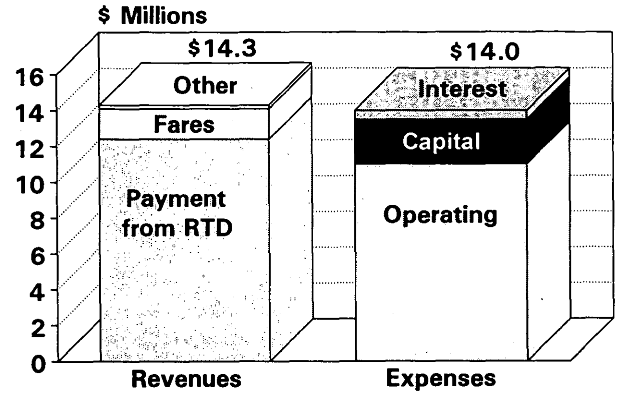

FIGURE 4 Contractors' probability.

projections because of

- Higher depreciation costs due to the addition of RTD's new $32 million RTD district shops and operations center complex and, to a lesser extent, new buses;
- Lower contractor invoice costs than projected;
- Lower RTD labor costs charged to privatization (offset by a larger portion of retained function costs, as described earlier); and
- Lower underutilized labor costs due to higher-than-projected attrition of mechanics.

ANALYSIS OF CONTRACTORS' ACTUAL COSTS AND PROFITABILITY

Figure 4 gives a summary of the analysis of the contractors' actual costs and profit on expenses. The analysis was based on financial statements provided by the contractors. Profitability was measured in terms of revenues less expenses for the local operations of each contractor. An allocation of corporate overhead expense was included, but it was not possible to analyze profitability from the overall corporate standpoint (e.g., return on investment or return on equity) because of the unavailability of overall corporate financial statements.

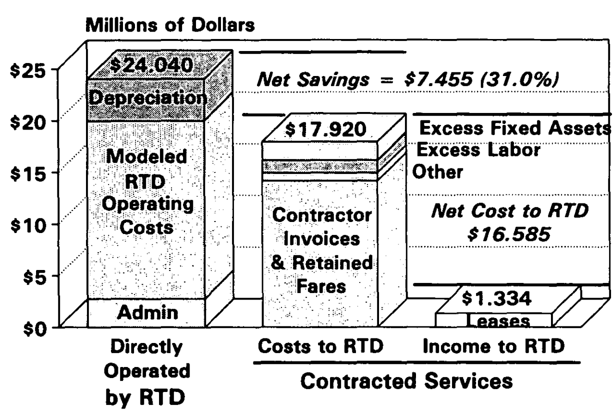

FIGURE 3 Fully allocated cost comparison (with capital costs).

This analysis determined that the contractors earned a profit of $337,000 out of total expenses of $14.0 million, or 2.4 percent. This compares to a loss of $217,000, or 2.1 percent, during the first year of privatized service.

SAFETY AND QUALITY OF SERVICE

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

- Local/limited radial routes: routes operating largely on surface streets and either passing through or terminating in downtown Denver. Limited routes operate over the same streets as local routes but make fewer stops; they operate primarily during the peak periods. The contractors provided 8 percent of systemwide local/limited radial service.
- Local/limited nonradial routes: routes operating largely on surface streets but not entering downtown Denver. These routes, sometimes referred to as "cross-towns," generally encounter less congested streets. The contractors provided 52 percent of systemwide local/limited nonradial service.
- Express routes: routes between suburban park-and-ride lots and the Market Street Station or the Civic Center Station in downtown Denver. The contractors provided 26 percent of systemwide express service.

Safety

Figures 5 and 6 show safety performance in terms of bodily injury and property-damage accident rates. Bodily injury accidents (per 100,000 passengers) are vehicle and nonvehicle accidents that involved injury to a passenger or other person. The contractor's rate was 40 percent lower than RTD's on local/limited radial routes and 26 percent higher on local/limited nonradial routes. There was no significant difference between RTD and the contractors on express routes.

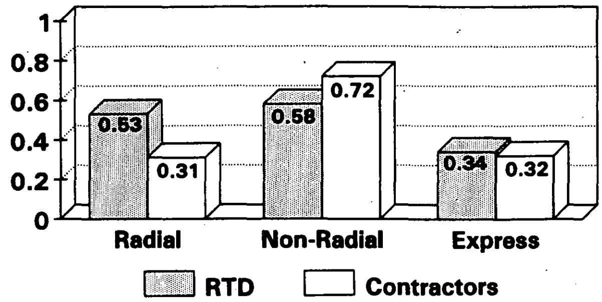

FIGURE 5 Bodily injury accidents per 100,000 passengers.

Property-damage accidents (per 100,000 vehicle-mi) are vehicle accidents that did not involve an injury. The contractor's rate was 22 percent lower than RTD's on local/limited radial routes and 15 percent lower on express routes. There was no significant difference between RTD and the contractors on the local/limited nonradial routes.

On-Time Performance

Figure 7 summarizes on-time performance, which addressed the conformance of bus arrival times to RTD schedule adherence standards. Buses more than 5 min later than scheduled were defined as late, and buses more than 1 min earlier than scheduled were early.

On-time performance was measured by RTD traffic checkers at selected time-points for local/limited radial and nonradial routes. On-time performance of express routes was measured at the Market Street and Civic Center stations for all trips. Early arrivals of the express routes were ignored since passengers were not inconvenienced.

The 1990–1991 on-time performance of RTD and the contractors was similar overall, with the contractors running early less often on the local/limited nonradial routes. Both RTD and the contractors improved on-time performance over 1989–1990.

Maintenance Reliability

Maintenance reliability was measured on the basis of the rate of vehicle miles between mechanical road calls (as recorded

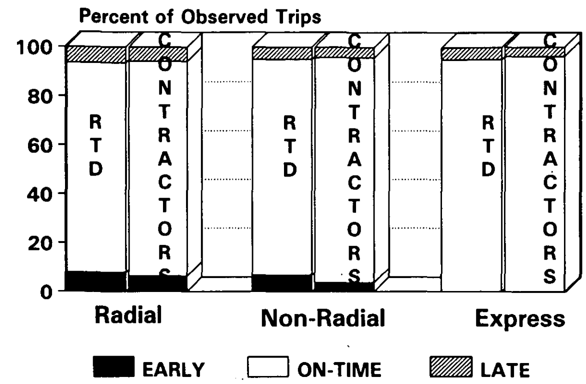

FIGURE 7 On-time performance.

by the RTD dispatch center). A higher value indicates better performance. This included road calls due to mechanical failure or the need to replace a bus for mechanic reasons. It did not include road calls due to operator requests for a supervisor, accidents, passenger illness, or other emergencies.

The comparison in Figure 8 was limited to the April–June quarter because route-level data were not available before April 1990. In April–June 1991, the contractors' maintenance reliability performance was 45 percent worse than RTD's on local/limited radial and 54 percent worse on nonradial routes. There was no significant difference between RTD and the contractors on express routes.

Complaints and Commendations

Complaints and commendations were measured on the basis of the rate of complaints per 100,000 passengers received at RTD's telephone information center.

Operator Performance Complaints

Operator performance complaints included charges of driving carelessly, acting with discourtesy, not knowing the route, failing to call stops, using improper procedures (which included other, unclassified complaints), providing incorrect information to passengers, passing a bus stop, passing a passenger waiting for a bus, and causing a passenger to miss a

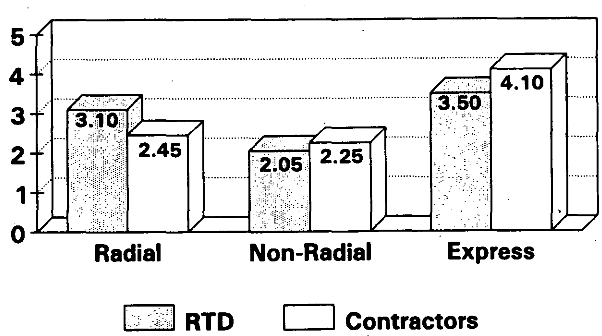

FIGURE 6 Property-damage accidents per 100,000 vehicle-mi.

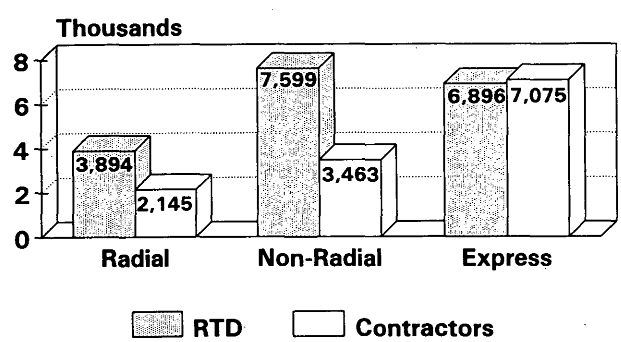

FIGURE 8 Maintenance reliability: miles between mechanical road calls.

transfer. The contractors' experience was 36 percent worse than RTD on local/limited radial routes, similar on local/limited nonradial routes, and 24 percent better than RTD on express routes.

Maintenance Complaints

Maintenance complaints addressed problems with the mechanical condition and the cleanliness of the bus. Local/limited radial and nonradial route complaints were negligible for both RTD and the contractors. The complaint rates for both RTD and the contractors were negligible on local/limited radial and nonradial routes. The contractors' complaint rate was 22 percent higher than RTD's on express routes.

On-Time Performance Complaints

The contractors' "early" complaints were not significantly different from RTD's on local/limited radial and nonradial routes; the contractors' complaints were 65 percent lower on express routes.

RTD's and the contractors' "late" complaint rate was negligible on local/limited radials and nonradials. The contractors' rate was 65 percent lower than RTD's on express routes. For RTD and the contractors, the "no-show" complaint rate was also negligible on local/limited radial and nonradial routes. The contractors' rate was 26 percent lower than RTD's on express routes.

Commendations

The contractors' commendation rate was similar to RTD's on local/limited radials, 46 percent better on local/limited nonradials, and 15 percent better on express routes.

CONTRACT COMPLIANCE

The contracts included provision for RTD to assess liquidated damages in those cases of observed lack of compliance by the contractors. Figure 9 summarizes the number of liquidated damages incidents, by contract provision, assessed by RTD in each of the first 2 years of privatization. The most frequently assessed liquidated damages continued to be those regarding on-time performance and nonfunctioning wheelchair lifts. Assessments equaled 0.25 percent of contractors' costs in 1990–1991, compared with 0.29 percent in 1989–1990.

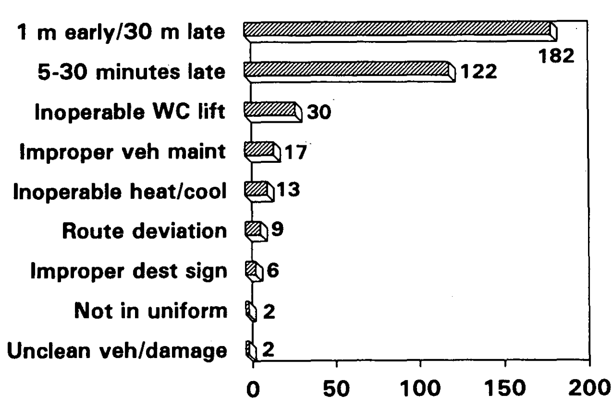

FIGURE 9 Liquidated damages assessments.

MAINTENANCE REVIEW

A review of the contractors' maintenance activities was undertaken to determine if they were properly following the maintenance standards specified in their contracts with RTD and in their vehicle leases. The review included inspections of the contractors' maintenance facilities, review of maintenance procedures, observation of maintenance activities, and spot inspections of randomly selected vehicles. This review was undertaken by Transportation Support Group, Inc.

The contracts between RTD and the contractors required buses to be maintained in a clean and safe condition. Periodic maintenance was required, and deferring maintenance was prohibited. Specifically, the contracts required

- Daily cleaning of bus interiors and exteriors;
- All preventative maintenance performed at regularly scheduled intervals, as specified in the manufacturers' maintenance manuals, within 1,000 mi of the scheduled interval;
- Wheelchair lifts maintained in a ready and usable condition when in revenue service;
- Body and exterior surfaces maintained in a safe, sound, and accident-free condition;
- Non-safety-related accident damage repaired within 3 weeks of occurrence; and
- Functioning heating and cooling systems.

The leases of RTD buses included specific bus maintenance and cleaning program requirements:

- Maintenance personnel: knowledge of buses and their components, tools and equipment, maintenance procedures, inspection procedures, repair procedures, and engine, transmission, and electrical system diagnosis.
- Bus cleaning: daily interior and exterior cleans, bimonthly (or every 2,000 mi) interior washing.
- Preventative maintenance, warranty work, quality control
  - –Maintenance within 1,000 mi of specified mileage intervals for components, assemblies, and systems;
  - –Maintenance performed to ensure that warranties remain valid;
  - –Components changed out at specified intervals;
  - –Conformance to all federal, state, and local exhaust requirements; and
  - –Alignments performed annually or as needed.
- Mechanical maintenance program: the following components inspected, serviced, and repaired or replaced at specified intervals and in safe and working condition before a vehicle enters revenue service or at all times:
  - –Wheelchair lifts;
  - –Brakes;

–Engine oil;
–Body and frame;
–Mechanical, electrical, fluid, air, and hydraulic systems;
–Interior free from exhaust fumes;
–Heating and air-conditioning systems; and
–Seats.

In addition, the contractors were required to maintain a sufficient spare parts inventory.

• Maintenance recording system: up-to-date vehicle file maintained for each vehicle and copies of inspection reports routinely submitted to RTD.

Figure 10 illustrates the maintenance staffing levels of the contractors and compares these levels with similar privately operated transit systems and with RTD and its public-sector peers. The contractors' maintenance staffing was relatively lean for mechanics but comparable for support staff (cleaners, shifters, utility workers). This may be partly explained by the relatively low age of the contractors' fleets, as shown in Figure 11.

Figure 12 portrays the results of inspections of randomly inspected vehicles. Of 155 buses on the contractors' properties, 21 (or 14 percent) were randomly selected for inspection. Buses were inspected for 22 specific maintenance areas. On the basis of the inspection of the contractors' maintenance facilities, review of maintenance procedures, and spot inspection of randomly selected buses, the following observations were made:

• Eleven of the 21 contractors' buses that were inspected were used, or were planned to be used, in transit service with safety-related conditions apparent (e.g., marginal or smooth tire treads, passenger doors opening and closing fast, long brakes, and cracked windshield glass).

• Lack of measured filling system for engine oil and transmission fluid was sometimes leading to under- or overfill conditions.

• The contractors stored some buses in unpaved parking areas, contributing to dusty conditions on some buses.

• All contractors were using the RTD maintenance reporting system forms.

• The contractors' maintenance tools and service equipment were adequate.

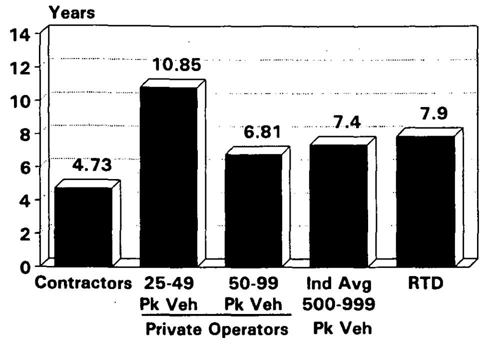

FIGURE 11 Average vehicle age.

SOURCE OF SAVINGS RESULTING FROM PRIVATIZATION AND ANALYSIS OF BUS OPERATOR WAGES AND TURNOVER

Source of Savings

Figure 13 summarizes the differences between RTD's actual incremental costs (based on the cost allocation model) and the contractors' actual costs. In terms of operating costs alone, more than half of the savings in actual costs was due to the lower wages and fringe benefits paid by the contractors. With capital costs included, bus operator and maintenance worker wages and fringe benefits accounted for more than 46 percent of the difference between RTD's and the contractors' costs.

The average costs of bus operator wages and fringe benefits per revenue hour of service were $24.44 for RTD and $14.20 for the contractors (41.9 percent lower than RTD).

RTD and contractor bus operator wages and turnover were analyzed in order to address the underlying sources of the savings identified earlier.

Wage Comparison

Figure 14 is a comparison of the wage rates paid by RTD and the contractors. The wage rate is determined by length of service. The RTD rates shown are for both full- and part-time bus operators. The contractors' wage rates are effectively full-time rates.

RTD's operator work force was predominantly at the top of the progression. More than 86 percent were at the top wage

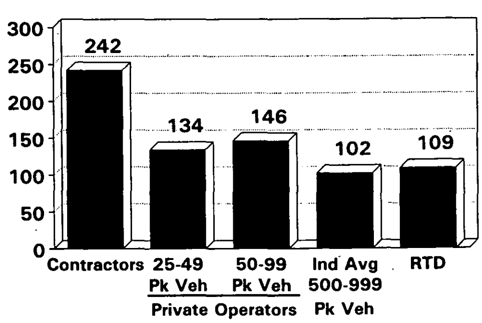

FIGURE 10 Maintenance staffing: thousands of vehicle miles per mechanic.

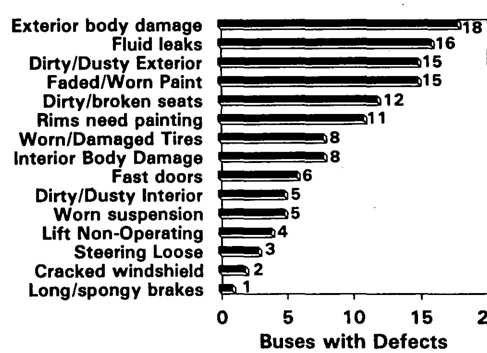

FIGURE 12 Maintenance defects: 21 inspected buses.

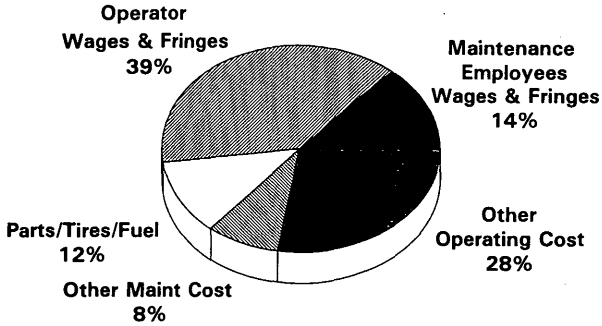

FIGURE 13 Source of operating cost savings.

rate, with more than 3 years of experience, as of the pay period ending June 22, 1991. The contractors' work force, being on the job for a shorter time, were not as high up the progression.

RTD hired nearly all of its bus operators as part-time employees and promoted them to full-time positions as vacancies occurred. The labor agreement allowed RTD a maximum number of part-time bus operators not to exceed 20 percent of its number of full-time bus operators. Thus, wage rate comparisons with the contractors should consider the RTD's part-time wage rate, at least during the first several years of privatized service.

Bus Operator Turnover Comparison

Figure 15 presents the turnover of RTD and contractor bus operators in terms of the percentage of bus operators resigned or terminated for cause after each 3 months of employment. RTD's experience is expressed in terms of operators hired during two periods:

- Since April 1989: only those bus operators hired during the same period of time that the contractors were hiring.
- Since January 1985: a stable period of hiring, extending several years before the impact of privatization. RTD reduced its hiring of bus operators in the year before the initiation of privatized services in order to minimize the financial impacts of the no-layoff provisions of SB 164. The attrition rate was

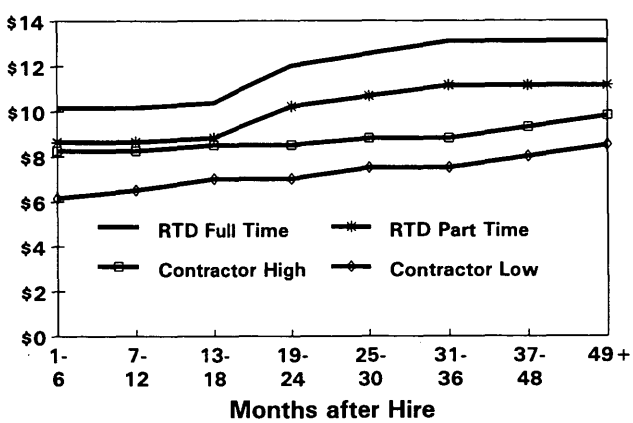

FIGURE 14 Bus operator hourly wage rates.

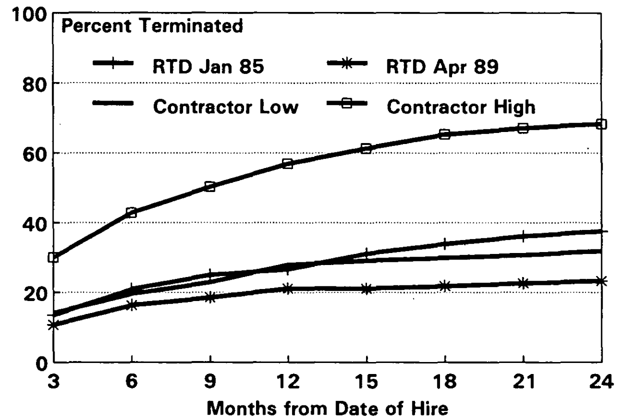

FIGURE 15 Bus operator resignations and terminations.

higher when the contractors initiated their hiring (particularly from April through November 1989).

The contractors experienced a significant range in rates of resignations and terminations for cause. The contractor with the lowest rate was similar to RTD's rate for operators hired since January 1985: nearly identical for the first 15 months of employment and actually lower than RTD's experience from 15 to 24 months of employment.

RTD's rate of resignations and terminations for cause was lower for its most recently hired bus operators, and this rate was lower than that experienced by the contractors. In terms of those bus operators hired since April 1989, after 24 months of employment RTD retained 12 percent more bus operators than the contractor with the best experience and 143 percent more than the contractor with the worst experience.

RTD's attrition before and after the contractors' peak hiring (April though November 1989) should be considered the norm, because RTD experienced a large number of resignations during the contractors' peak hiring, particularly of part-time bus operators who sought full-time positions with the contractors.

Figure 16 compares the causes of bus operator terminations at RTD and the contractors. Overall the experience was similar, with a larger proportion of RTD bus operators resigning during the contractors' peak hiring period..There was no indication that lower wages had a significant impact on the relative mix of terminations for cause and due to resignation.

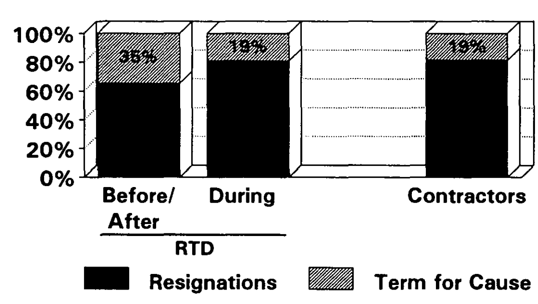

FIGURE 16 Bus operator turnover (RTD before, after, and during contractors' peak hiring).

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Strategic Planning for Transit Agencies in Small Urbanized Areas

Daniel K. Boyle and Paul E. Ouderkirk

An approach taken by the Center for Urban Transportation Research (CUTR) to strategic planning for a transit agency in small urbanized areas is presented. The impetus for the project was the requirement of Florida Department of Transportation that all recipients of public transit block grants prepare a transit development plan. CUTR defined its role as organizing the relevant information needed to develop and support a strategic viewpoint. Information on perceptions of the transit system was sought from three groups: current riders, nonusers, and community leaders. Different techniques, including interviews, focus groups, and onboard surveys, were used to elicit information from these groups. The main advantage of this three-pronged approach was that a full range of perceptions and issues was identified, resulting in sound recommendations that reflect a clear strategic direction.

An approach to the development of a strategic plan for a small transit system is described. The state of Florida requires all recipients of public transit block grants to prepare a transit development plan (TDP). In interpreting how this requirement is to be met, the Florida Department of Transportation (FDOT) has described the ideal TDP as a reflection of a strategic planning process (*1*). Salient plan characteristics include an exclusive concentration on transit, an emphasis on transit's role at the community level, and explicit consideration of external factors affecting the viability of the transit system. The most noteworthy aspect of the process is that the state is encouraging the transit properties to go beyond routine service and financial plans to incorporate strategic considerations.

This paper is intended to demonstrate ways in which elements of strategic planning may be incorporated into the TDP. As an example, the approach used by the Center for Urban Transportation Research (CUTR) in preparing TDPs for three transit agencies in small urbanized areas is discussed, and strengths and weaknesses inherent in this approach are evaluated. Although the focus is on the process as opposed to the results, the concluding section presents sample findings and suggests measures by which the ultimate success of these plans may be judged.

STRATEGIC PLANNING AND TRANSIT

One intriguing aspect of the TDP process is that it encourages a transit manager to step back from the all-encompassing day-to-day operating concerns and take a longer view of the transit system. Strategic factors that affect an agency's long-term success may be summarized in terms of strengths, weaknesses, opportunities, and threats (*2*). There is no single correct formula for carrying out strategic planning, but a checklist of related processes and issues prepared by TRB's Committee on Strategic Management is a useful starting point. The checklist includes the following items:

- Organization mission: What is the agency's purpose? Where does it want to be in 5 years?
- Environmental scanning: What role do factors outside the agency play in its ability to achieve its mission? What effect might external trends have on the agency?
- Market analysis: Who are the customers? Who might be customers in the future? Are there markets currently unserved? Can the agency identify new markets? Is the agency oriented toward its customers?
- Strengths and limitations: What does the agency do well? What aspects of agency performance are not adequate?
- Stakeholders: Who are the agency's friends? Who cares about whether the agency is successful? Who are its enemies?
- Opportunities and threats: What areas can lead to future growth and success? Are there factors that threaten the agency's ability to carry out its mission?
- Critical issues and strategies: What areas are essential to the agency's success? Which strategies should be pursued?
- Strategic management: In what ways is the agency changing? How can change be managed?

Most transit agencies do not routinely consider these issues in their day-to-day operations. Some may have adopted a mission or goal statement, and a few may consider trends and markets, but more immediate crises tend to crowd out long-term concerns.

A major challenge facing transit is that it is often viewed as a social service instead of a travel option. This is especially true in smaller, less dense urbanized areas with little traffic congestion and no parking problems. The effect of the automobile on urban form has heightened this perception. As urbanized areas become more suburbanized, the automobile is increasingly seen as an absolute necessity. The perception that transit is only for those with no choice is a natural outcome.

This perception has serious strategic implications for the transit agency. The agency is confronted with a limited market for its services, little prospect for growth, and few stakeholders. The TDP can provide a blueprint for recognizing and possibly changing negative perceptions. By focusing on the

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needs of transit, the TDP can also counter the tendency of comprehensive plans in smaller urbanized areas to emphasize highway projects.

DESIGNING A PLAN TO OBTAIN NECESSARY DATA

The TDP framework discussed in this paper is based on a methodology developed by FDOT (*1*). The intent is to construct a policy document that addresses strategic issues, considers mobility needs within the context of overall planning and development efforts, and includes a staged implementation plan to meet these needs.

The FDOT methodology recommends the use of several measures to quantify the mobility needs of an area, including community involvement tools such as surveys and public meetings. The data collection strategies used by CUTR expand on the FDOT suggestions; they were designed to provide a quantitative and a subjective basis for identifying mobility needs and developing the most effective strategies for meeting the needs. CUTR concentrated its data collection strategies on three groups: community leaders, transit riders, and nonusers. The following strategies were used:

- Interviews with key persons. Appropriate key persons were identified by the metropolitan planning organization. Key persons may include local elected officials, department heads, business leaders, and civic representatives. The interviews are intended to identify policy issues of greatest concern, perceptions of existing transit service, recommendations for improvements, and the dynamics of existing organizational relationships.
- On-board surveys. On-board surveys provide valuable insights into demographic characteristics, travel behavior, and transit users' opinions of existing service. Demographic profiles of transit riders can be compared with characteristics of the population at large to identify more precisely the composition of the market market. Information on travel patterns, alternative modes, and frequency of system use clarifies the nature of existing transit demand. Finally, the user can offer unique and pragmatic insights into the system's advantages and shortcomings. In some cases, CUTR has also surveyed bus operators to tap their knowledge of the transit system and enlist their cooperation in the conduct of the on-board survey.
- Nonuser surveys. One innovative aspect of CUTR's approach is in the use of focus groups to obtain information on nonusers' travel decisions. The informal, open-ended nature of focus groups encourages participation and allows important issues to surface in the course of group conversation. The results of a focus group session are in no way statistically valid as a representation of the nonuser population, but focus groups excel in raising ideas and issues for further consideration.

The results of the interviews, surveys, and focus groups provided a clear assessment of transit needs. Other methods were used to estimate potential demand for transit, and to identify strengths and weaknesses. Peer review was used to gauge positive and negative aspects of the transit system. CUTR has collected and analyzed transit performance measures from around the country, with a particular focus on Florida systems (*3*). Peer review provides a quantitative assessment of the performance of a given transit system compared with similar systems elsewhere.

Taken together, the results obtained from these techniques form a clear picture of the role played by the transit system in the community. Strengths and weaknesses, community perceptions, system performance, stakeholders, potential markets, critical issues, and possible strategic directions are all identified through this approach.

LOCAL INVOLVEMENT IN TDP

The broad mandate of addressing the role of transit in the community necessitates the involvement not only of the transit agency but also of community members. Along with the interviews, surveys, and focus groups, a local review committee was established to provide public input and review reports. Community members contributed to discussions of goals and objectives, the on-board survey instrument, and recommendations.

A key to the success of each project was the involvement of the transit agency. For strategic planning to be successful, an organization must make a commitment to the process (*4*,p.128;*5*). Strategic planning by an outsider is a contradiction in terms. CUTR defined its role as providing the tools (data collection techniques) and in some sense the framework (a focus on where the agency wants to be in 5 years) for considering long-term issues. CUTR made a special effort to keep transit management informed at every step of the project, an effort that alleviated concerns about an outside agency dictating solutions without local input. This effort and the informal nature of contacts were major factors in gaining the involvement of the transit agency.

In small, automobile-dominated cities, the transit agency is often forced to work in a reactive mode, because few stakeholders are willing and able to exert power and influence on its behalf. Difficulty in mobilizing support was the major reason that many of the suggestions for improvements had not been implemented in the past. By its nature, the TDP is a means to gain support for transit. In its guidelines, FDOT emphasized the exclusive focus on transit services as a major distinguishing characteristic of a TDP. The plan has the potential to create a more level playing field in setting transportation priorities within the metropolitan area. This result is paradoxical from the strategic planning perspective. Despite the importance of local involvement in the strategic planning process, the fact that an outsider prepares the recommendations may carry more weight with decision makers and make implementation more likely than if the transit agency had made these recommendations itself.

CONCLUSIONS

Summary

The focus of this paper has been on the approach used by the CUTR in preparing TDPs for three small urbanized areas. Although not solely strategic in nature, the TDP incorporates many elements of strategic planning, including

- Organizing mission and goals;
- Analyzing external trends, existing and potential markets, and opportunities;
- Identifying stakeholders; and
- Priority ranking improvements.

Recognizing that strategic planning cannot be done effectively by an outsider, CUTR acted as a facilitator in the process. Small transit agencies are typically understaffed and must focus almost exclusively on the day-to-day details. The long-range view is a luxury under these conditions. CUTR defined its role as organizing the relevant information needed to develop and support a strategic viewpoint.

The approach adopted in this project sought information from three major groups: local elected officials and community leaders, transit riders, and nonusers.

Interviews with key local officials provided insight into community perceptions of transit and identified stakeholders. Onboard survey results defined demographic characteristics of riders, provided information about travel behavior and needs, and revealed riders' perceptions and attitudes toward the system. Focus groups with nonusers elicited reasons for this group's travel behavior and nonuse of transit.

Example Cases

This paper has specifically addressed the process rather than the results of the strategic planning effort. It may be useful in closing to provide examples of how this approach can lead to very different findings.

In one urbanized area, community leaders stated in the interviews that residents knew about the transit system but chose not to use it. In both focus groups, however, the first and most strongly expressed reason for not using transit was that the individual did not have enough information about bus destinations, routes, stops, and schedules. This finding strongly suggested the need for an information and marketing effort, a recommendation that would not have been developed from the interview results alone. Within 6 months of the plan's completion, the transit agency created and filled a marketing position.

In a second urbanized area, the interviews revealed a strong unwillingness to provide local funding for the transit system. A closer examination of the agency's financial status revealed a need to strengthen the financial reporting function to ensure that community leaders had a clear understanding of fiscal needs.

In a third urbanized area, survey responses pinpointed service reliability as a major problem. This could be traced to the age of the bus fleet and the decline in spending for maintenance over a period of several years. Marketing issues were also important here, but service problems received top priority.

One weakness in the approach described here occurred in the goal-setting process. This was scheduled early in the project, before the transit agency had overcome its reservations about the usefulness of this effort, and resulted in little local involvement in goal setting. In subsequent projects, the goals and objectives task was scheduled later, after a cooperative relationship had been established and the interviews, surveys, and focus groups had yielded data on perceptions and problems.

The three-part approach to gathering information from distinct groups worked extremely well. Virtually all of the recommendations advanced in the final TDPs were identified through one or more of these techniques. Taken together, the results of this approach clarified community goals and policies with respect to transit, identified potential new markets for the transit system, clearly revealed transit stakeholders, highlighted critical issues, and delineated the strengths and weaknesses of the transit system.

The ultimate success of this approach is yet to be determined, but it is possible to outline how success might be measured. The TDP process should result in increased ridership (as latent mobility needs are met), improved customer satisfaction, additional funding for the system, and a better image for transit in the broader community.

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Method for Optimizing Transit Service Coverage

LAZAR N. SPASOVIC AND PAUL M. SCHONFELD

A method is presented for determining the optimal length of transit routes that extend radially from the central business district (CBD) into low-density suburbs. In addition to the route length, the route spacing, headway, and stop locations are also optimized. The equations for the route length, route spacing, headway, and stop spacing that minimize the sum of operator and user costs are derived analytically for many-to-one travel patterns with uniform passenger trip density. These equations provide considerable insight into the optimality conditions and interrelations among variables. The equations are also incorporated within an efficient algorithm that computes the optimal values of decision variables for a more realistic model with vehicle capacity constraints. The algorithm is applied to rectangular and wedge-shaped urban corridors with uniform and linearly decreasing passenger densities. The results show that in order to minimize the total cost, the operator cost, user access cost, and user wait cost should be equalized. At the optimum, the total cost function is rather shallow, thus facilitating the tailoring of design variables to the actual street network and particular operating schedule without substantial cost increases. The actual stop spacing pattern is determined for each corridor type. For a uniform passenger density, the stop spacing increases along the route in the direction of passenger accumulation toward the CBD. For a linearly decreasing passenger density, the stop spacing first decreases and then increases along the route toward the CBD. The sensitivity of design variables to some important exogenous factors is also presented.

One of the main problems in designing transit services is to provide appropriate transit service coverage and particularly to determine how far outward to extend transit routes into low-density suburbs. Service operators and users have somewhat conflicting objectives regarding the transit route length. Operators prefer short routes in order to minimize their costs. Passengers, especially those from the outer suburbs, prefer longer routes in order to minimize their access impedance. Since the route length has a significant impact on both operator costs and passenger impedance, its value should be carefully selected.

The purpose of this paper is to develop a method for optimizing the length of transit routes that extend radially outward from the central business district (CBD). However, this problem may not be considered independent of route location and service scheduling. Therefore, the problem considered here is finding optimal combinations of route length, route spacing, headway, and stop location and spacing that minimize the sum of operator and user costs for rectangular and wedge-shaped urban corridors with uniform and linearly decreasing passenger trip densities.

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LITERATURE REVIEW

Several previous studies sought to optimize various elements of transit network design and service using calculus and, to a lesser extent, mathematical programming methods (*1–18*). The summary of pertinent analytical models that are classified according to the design variable(s) optimized is presented in Table 1. The table shows that in most studies the travel demand was fixed and uniformly distributed over the service area. The usual travel pattern was many-to-one, which is typical for suburb-to-CBD commuting. The most common objective function was minimization of the sum of operator cost and user time cost.

A literature review revealed only one published paper (*15*) that optimized the radial length of a transit route in an urban transportation corridor, which is the focus of this research. Given the significant impact of the route length on cost, it is rather surprising that this research topic has not been given more attention in the literature. Wirasinghe and Seneviratne presented an analytical method for deriving the optimal length of a rail transit line in an urban corridor currently served by bus (*15*). The objective function to be minimized included the total cost of rail fleet, rail and bus operating cost, and passenger time cost. The authors found that for nonuniform rail line cost there could be several line lengths at which the total transit system cost is locally minimized (or maximized). For uniform rail line cost, an optimal line length existed if the net gain in travel time and operating cost of transporting the total demand a unit distance by rail when compared with bus exceeded the marginal line and fleet cost per unit length. The authors developed closed-form solutions for the line length for sectorial and rectangular corridors with uniformly distributed demand.

That paper did not consider stations along the line and related access cost. Furthermore, by basing the minimum rail fleet size on peak-period passenger capacity requirements, the authors assumed that the route would operate at the maximum allowable headway. This assumption may be unwarranted even for the peak periods since the optimal headway may be heavily influenced by user waiting time. The present work not only optimizes route length but also jointly optimizes the headway, route, and stop spacing.

TABLE 1 Summary of Pertinent Analytical Models for Transit Network Design

Decision Variables	Objective Function	Transit Mode	Street Network Geometry	Passenger Demand	Authors
Route Length	Min. operator and user cost	rail	rectangular grid	General, inelastic, many-to-one	Wirasinghe and Seneviratne (1986)
Zone Length, Headway	Min. operator and user cost	bus	rectangular grid	Piecewise uniform, inelastic,	Tsao and Schonfeld (1984)
Route Spacing, Lengths and Headway	Min. operator and user cost	bus and rail	rectangular grid	Uniform, inelastic, many-to-one	Byrne (1976)
Route Spacing	Min. operator and user cost	bus	rectangular grid	Uniform, inelastic, many-to-many	Holroyd (1967)
Route Spacing and Headway	Min. operator and user cost	bus	rectangular grid	Uniform, inelastic, many-to-one	Byrne and Vuchic (1972)
Route Density and Frequency	Min. operator and user cost	bus	rectangular grid	General linear, inelastic, many-to-one	Hurdle (1973)
Route Spacing, Headway and Fare	Max. operator profit, Max. user benefit, etc.	bus	rectangular grid	Uniform Elastic, many-to-one	Kocur and Hendrickson (1982)
Route Spacing, Headway and Stop Spacing	Min. operator and user cost	feeder bus to rail	rectangular grid	General, inelastic, many-to-one	Kuah and Perl (1988)
Route Spacing, Headway and Fare	Max. profit, max. welfare, min. cost	bus	rectangular grid	Irregular, elastic, many-to-many, time dependent	Chang and Schonfeld (1989)
Route Spacing, Zone Length, Headway	Min. operator and user cost	bus	rectangular grid	Uniform, inelastic, many-to-one	Chang and Schonfeld (1993)
Station Location and Spacing	Min. total user travel time	rail	linear	Uniform, inelastic, many-to-one	Vuchic and Newell (1968)
Stop Location and Spacing	Min. operator and user cost	rail	rectangular grid	Uniform, inelastic, many-to-one	Hurdle and Wirasinghe (1980)
Stop Spacing	Min. operator and user cost	bus	radial	General, inelastic, many-to-many	Wirasinghe and Ghoneim (1981)

STUDY APPROACH

The problem is to provide optimal transit service coverage in an urban corridor shown in Figure 1. The corridor of length E and width Y is divided into two zones. Zone 1 consists of the area between the CBD and the route terminus. Zone 2 is area between the route terminus and the end of the corridor.

The basic approach in this research is to develop a total cost function in which the various operator and user cost components are formulated as functions of several decision variables, namely, route length, headway, route spacing, and stop spacing. Optimal stop locations as well as stop spacing are determined. The design objective in determining the optimal service area coverage is to minimize the total operator and user cost. The optimal values of the decision variables are found by taking partial derivatives of the objective function of all decision variables, setting them equal to 0, and solving them simultaneously. This approach, as it will be seen later, resulted in a simple model that offered considerable insight into the optimality conditions and interrelations among variables. The equations obtained are incorporated within an efficient algorithm that determines decision variable values for a more realistic model that includes a service quality constraint.

This analysis of optimal transit service coverage is based largely on Spasovic's master's thesis (*16*), in which more detailed derivations and results can be found.

Simple Model

The following assumptions are made in this model:

1. The corridor is served by a transit system consisting of n parallel routes of uniform length L, separated by a lateral spacing M.

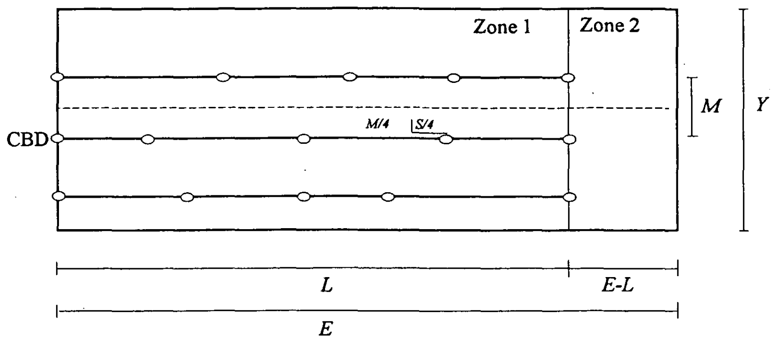


FIGURE 1 Corridor and transit network under study.

2. The routes extend from the CBD outward.
3. The total transit demand is uniformly distributed along the entire corridor, over time, and is insensitive to the quality of transit service.
4. The commuter travel pattern consists of many-to-one or one-to-many trips focused on the CBD.
5. Passengers board and exit transit vehicles only at stops along the route.
6. A very dense rectangular grid street network allows passengers orthogonal access movements (i.e., parallel and perpendicular to the route).
7. Transit vehicles operate in local service (i.e., all vehicles serve all stations).
8. The average access speed is constant. Walking is assumed to be the only access mode.
9. Average wait time is assumed to equal one-half of the headway. The headway is uniform along the route, as well as among all parallel routes.
10. Operator costs are limited to those for vehicles (i.e., infrastructure is freely available).
11. Demand does not exceed vehicle capacity.
12. There is no limit on vehicle fleet size.

The total cost objective function includes the operator cost C_o, and the user cost C_u. The operator cost represents the cost of resources used by the operator to provide the service. The user cost consists of the access, wait, and in-vehicle costs multiplied by their respective values of time.

The operator cost includes the maintenance and overhead as well as more direct costs of operation (driver wage, fuel, brake shoes, etc.). Vehicle depreciation might also be included as a portion of operator cost. In this paper, the operator cost is defined by the hourly operation cost c. The total hourly operator cost is the fleet size multiplied by the hourly operation cost. By definition, the fleet size is the number of on-line vehicles required to provide service and is obtained by dividing the total round-trip time (running time and layover time) by the headway. The average transit operating speed is selected to reflect running and layover times. Therefore, the total round-trip time is the round-trip route length divided by average speed. The stopping delay d is also included in deriving the operator cost. The delay d is a linear function of the number of people waiting for vehicles at stops and the passenger boarding rate:

$$d = \text{const.} + (\text{number of passengers})(\text{boarding time per passenger})$$

A constant delay due to acceleration and deceleration is assumed at each stop. The impact of these delays on the cost of operation is taken into account by multiplying the number of stops (given as $N = L/S$) by the stopping delay d and the operator hourly cost c. The total hourly operator cost is then

$$C_o = \frac{2cYL}{HM}\left(\frac{1}{V} + \frac{d}{S}\right) \quad (1)$$

where

c = vehicle operating cost (\$/veh-hr),
Y = corridor width (km),
L = length of transit route (km/route),
d = stopping delay (hr/stop),
H = route headway (hr/veh),
M = route spacing (km/route),
V = average transit speed (km/hr), and
S = average stop spacing (km/stop).

The hourly user cost, C_u, consists of the access (C_a), wait (C_w), and in-vehicle (C_{iv}) costs:

$$C_u = C_a + C_w + C_{iv} \quad (2)$$

Since the trip origins are uniformly distributed over the corridor served by parallel routes, an average passenger accessing the route perpendicularly walks one-quarter of the spacing between the two routes, for an access distance of $M/4$. The length of passenger access alongside the route depends on whether the trip originated within Zone 1 or Zone 2. A passenger from Zone 1 walks along the route one-quarter of the local stop spacing S before reaching the stop. Passengers originating in Zone 2 have no other choice but to board the route at the terminus, thus having an average access distance of $(E - L)/2 + M/4$. The total hourly user access cost, C_a, is then obtained by multiplying the average access distances by the value of access time (V_a) and the ridership, and dividing by the access speed (G). The total user access cost is then

$$C_a = \frac{V_a}{G}\left[\frac{(E - L)}{2}P(E - L)Y + \frac{S}{4}PLY + \frac{M}{4}PEY\right] \quad (3)$$

where E is corridor length in kilometers and P is passenger trip density in passengers per square kilometer hour.

The total waiting cost, C_w, equals the value of waiting time, V_w, multiplied by the average wait time per passenger ($H/2$) and by the total ridership (PEY).

$$C_w = \frac{V_w H}{2} PEY \tag{4}$$

The total user in-vehicle cost is obtained by multiplying the time that an average passenger spends in the vehicle by the value of in-vehicle time (V_{iv}) and the total number of passengers. In this model, the in-vehicle time consists of two parts: the actual riding time between the origin stop and CBD, and the additional delay due to stops at stations. The average in-vehicle riding time is obtained as the average distance traveled divided by the speed (V). Therefore, the passengers originating in Zone 1 travel about an average distance of $L/2$, and those from Zone 2 travel the whole length of the route L. Thus, the total user in-vehicle cost is given as

$$C_{iv} = V_{iv}\left[\frac{L}{2V}PYL + \frac{L}{V}P(E - L)Y + d\frac{L}{2S}PYL + d\frac{L}{S}PY(E - L)\right] \tag{5}$$

No out-of-pocket costs were included in the user costs. Transit fares are not part of the total cost since they are merely transfer payments from users to operators.

The hourly total system cost, TC, a sum of operator (Equation 1) and user costs (Equations 3–5) is then

$$TC(L,H,M,S) = \frac{2cYL}{HM}\left(\frac{1}{V} + \frac{d}{S}\right) + \frac{V_a}{G}PY\left[\frac{(E - L)^2}{2} + \frac{S}{4}L + \frac{M}{4}E\right] + \frac{V_w H}{2}PEY + V_{iv}PY\left[\frac{L^2}{2V} + \frac{L}{V}(E - L) + d\frac{L^2}{2S} + d\frac{L}{S}(E - L)\right] \tag{6}$$

The total cost function can be minimized by setting its partial derivatives with respect to the decision variables to 0. In this case, the partial derivatives of the optimization variables, the route length, headway, route spacing, and the stop spacing are

$$\frac{\partial TC(L)}{\partial L} = \frac{2cY}{HM}\left(\frac{1}{V} + \frac{d}{S}\right) + \frac{V_a}{G}PY\left[2\frac{(E - L)}{2}(-1) + \frac{S}{4}\right] + V_{iv}PY\left[\frac{L}{V} + \frac{E}{V} - \frac{2L}{V} + d\frac{L}{S} + d\frac{E}{S} - d\frac{2L}{S}\right] = 0 \tag{6a}$$

$$\frac{\partial TC(H)}{\partial H} = -\frac{2cYL}{H^2 M}\left(\frac{1}{V} + \frac{d}{S}\right) + \frac{V_w}{2}PEY = 0 \tag{6b}$$

$$\frac{\partial TC(M)}{\partial M} = -\frac{2cYL}{HM^2}\left(\frac{1}{V} + \frac{d}{S}\right) + \frac{V_a}{4G}PEY = 0 \tag{6c}$$

$$\frac{\partial TC(S)}{\partial S} = -\frac{2cYLd}{HMS^2} + \frac{V_a}{4G}PLY + V_{iv}PYL\left[-d\frac{L}{2S^2} - d\frac{1}{S^2}(E - L)\right] = 0 \tag{6d}$$

When Equations 6a–6d are solved independently, we obtain the following equations:

$$L^* = E - \frac{8cG\left(\frac{1}{V} + \frac{d}{S}\right) + PHMV_a S}{4\left[V_a - V_{iv}G\left(\frac{1}{V} + \frac{d}{S}\right)\right]PHM} \tag{7a}$$

$$H^* = \left[\frac{4cL\left(\frac{1}{V} + \frac{d}{S}\right)}{V_w MPE}\right]^{1/2} \tag{7b}$$

$$M^* = \left[\frac{8cLG\left(\frac{1}{V} + \frac{d}{S}\right)}{V_a HPE}\right]^{1/2} \tag{7c}$$

$$S^* = \left[\frac{4Gd(2c - V_{iv}PHM)\left(\frac{L}{2} - E\right)}{V_a HPM}\right]^{1/2} \tag{7d}$$

Several observations should be made here: when the route length, route spacing, headway, and stop spacing are optimized independently of each other, their relation to the other decision variables can be read directly from Equations 7a–7d. These equations provide the optimal value of one of the decision variables as a function of the other three variables and provide useful insights into the relations between the decision variables and parameters. For example, Equation 7a can be used to find the optimal route length when the headway, route spacing, and average stop spacing are given (e.g., to satisfy the minimum service standards). Such equations may be useful by themselves in some situations in which certain decisions variables such as the route length L or the stop spacing S cannot be modified. Unfortunately, Equations 7a–7d cannot be solved simultaneously using algebraic methods.

According to Equation 7a, the optimal route length varies directly with the corridor length E, passenger density P, operating headway H, route spacing M, value of access time V_a, transit speed V, and stop spacing S. It varies inversely with the vehicle operating cost c, and access speed G.

The optimal headway varies directly with the square root of operator cost, route length, and stopping delay. It varies inversely with the square root of the wait cost, passenger density, transit speed, corridor length, route spacing, and stop spacing.

The optimal route spacing varies directly with the square root of access speed, operator cost, route length, and stopping delay. It varies inversely with the square root of the access cost, passenger density, transit speed, corridor length, headway, and stop spacing.

Finally, the optimal average stop spacing varies directly with the square root of access speed, operator cost, and time lost per stop. It varies inversely with the square root of the access cost, passenger density, headway, route spacing, and in-vehicle cost.

More Realistic Model

Although the simple model provided valuable insights into the relationship among the decision variables and exogenous parameters, it is still too complex for the simultaneous optimization of all of the decision variables algebraically. To solve the model, a numerical algorithm was developed. In addition, some of the original assumptions were relaxed by the introduction of a vehicle capacity constraint. This constraint ensures that the total capacity provided on the routes satisfies the demand by restricting the maximum allowable headway; it is written as

$$PEY \leq K \frac{Y}{MH} l \qquad (8)$$

where K equals capacity of transit vehicle (in spaces), and l is the allowable peak load factor at the CBD.

Finally, the model can be written in the following form:

$$\begin{aligned} TC(L,H,M,S) = & \frac{2cYL}{HM}\left(\frac{1}{V} + \frac{d}{S}\right) \\ & + \frac{V_a}{G} PY\left[\frac{(E - L)^2}{2} + \frac{S}{4} L + \frac{M}{4} E\right] \\ & + \frac{V_w H}{2} PEY \\ & + V_{iv} PY\left[\frac{L^2}{2V} + \frac{L}{V}(E - L)\right. \\ & \left. + d\frac{L^2}{2S} + d\frac{L}{S}(E - L)\right] \end{aligned}$$

subject to

$$PEMH \leq Kl$$

$$L,H,M,S \geq 0$$

OPTIMIZATION ALGORITHM

The preceding model is formulated as a constrained optimization problem with nonlinear objective function and linear constraints. The model can be solved by using a penalty method (*20*) as an unconstrained optimization problem by pricing the constraint out of the constraint set and introducing it into the objective function with a penalty.

Instead of using the penalty function method, an algorithm was developed that sequentially applied Equations 7a–7d in somewhat modified form to advance from an initial feasible solution toward the optimal solution. The algorithm, shown in Figure 2, starts with a trivial feasible solution to the problem and in each step improves the value of the objective function by computing an optimal value of one decision variable while keeping the others at their feasible levels. In computing the optimal values of decision variables, the algorithm first computes the number of stops, then route length, route spacing, and finally headway. In each step, the value of a newly computed variable is recorded and used in the next step for computing the optimal values of other decision variables. The algorithm keeps improving the objective function until it converges to an optimal solution. The algorithm decides to terminate on the basis of two criteria. The first criterion examines whether the newly obtained optimal headway satisfies the capacity constraint—that is, it checks whether the optimal headway is smaller than maximum allowable headway. If the optimal headway is greater than the maximum allowable headway, the algorithm terminates. The optimal headway is set equal to the maximum allowable headway, and the last set of decision variables is considered an optimal solution. The second criterion determines that the values of total costs from two successive iterations are sufficiently close that no significant further improvement can be expected. Assuming that the optimal set of decision variables is reached, the program computes the values of the total cost function for the optimal route length, number of stops, and spacing (i.e., N^*,L^*,M^*) allowing variations in the headway, H. The purpose of this is to investigate the shape of the total cost near the optimum. As discussed later, the total cost turned out to be a relatively flat (shallow, four-dimensional, U-shaped) function. Thus, small deviations from the optimal decision variables result in even smaller relative changes in total cost.

Besides computing the optimal values of the decision variables very quickly, the algorithm allows us to incorporate a scanning procedure for deriving the actual location of stops along the route. Note that Equation 7d calculates an optimal value of the average stop spacing, thus implying uniform spacing along the route. Although a uniform spacing is quite common on bus transit routes in urban areas with grid street networks (e.g., Philadelphia and Manhattan), it does not yield the optimal solution for our objective function that minimizes the total user and operator costs. Intuitively, one might see that the actual stop location, thus spacing, will vary along the line as a result of the trade-off between the delay cost at stops incurred by the operator and passengers aboard the vehicles and the access cost of passengers boarding the vehicle along the route. Therefore, a scanning approach is incorporated in the algorithm to optimize variable stop spacing along transit routes. This scanning algorithm is somewhat similar to a method presented by Newell (*4*) and Hurdle (*6*). They integrated the demand function over time and dispatched the vehicle each time the optimum condition was reached. Wirasinghe used a somewhat analogous integration procedure over space to locate stops on feeder bus routes when the function of cumulative number of stations reached an integer (*10*). Chang and Schonfeld used a similar approach to optimize the lengths of bus service zones (*18*).

The partial total cost equation, derivation of formulas for optimal decision variables that are used in the algorithm, and description of the scanning procedure for determining the actual location of the stops are described in the following.

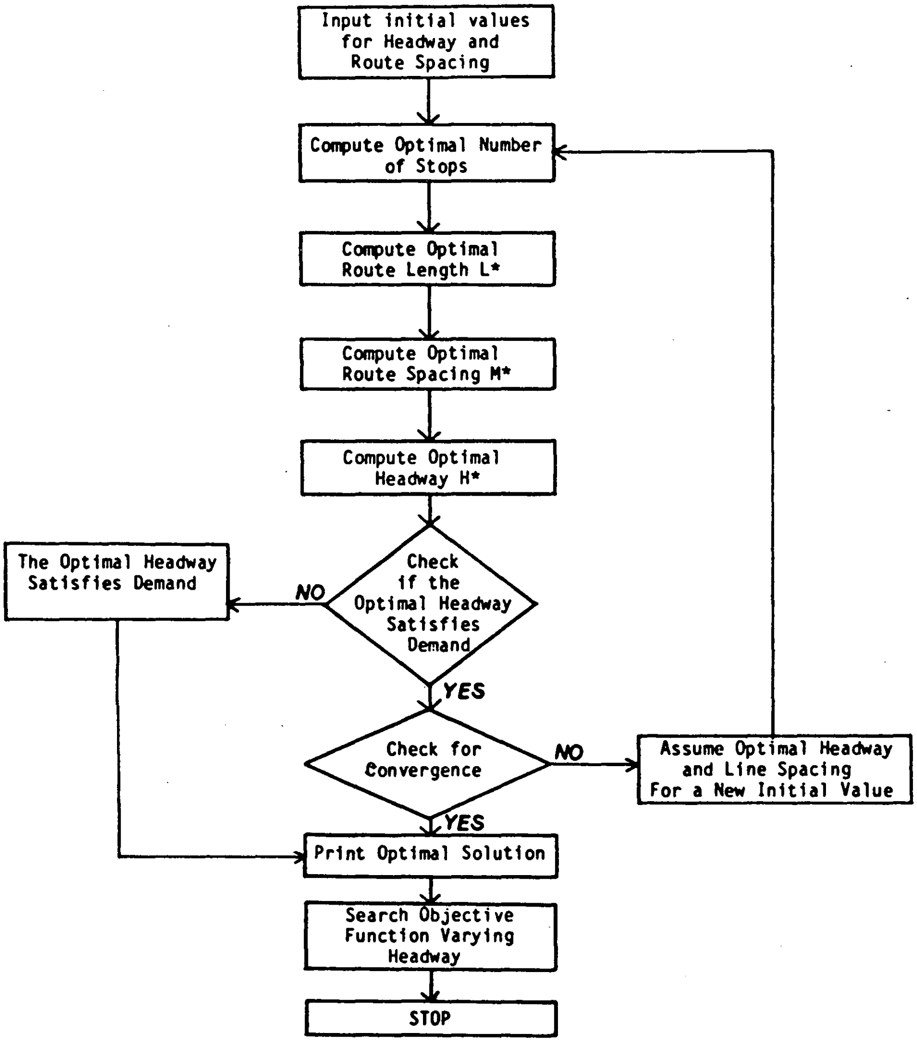


FIGURE 2 Optimization algorithm.

Optimal Number of Stops and Stop Spacing

The local station spacing on a route depends on trade-offs between delays to vehicles and passengers already on board versus the passengers' access cost. Clearly, under the objective of minimizing the total cost, the vehicle traveling on the route will not stop if the combined cost of delaying the passengers aboard the vehicle and operator cost outweighs the access cost of passengers waiting along the route.

To apply such logic in determining actual stop locations, the corridor was partitioned into a finite number of small areas, ΔX, and scanned from its end toward the CBD. At any point along the route at X distance from CBD, and for the small increment ΔX (e.g., 0.1 km), the number of people within the increment as well as the cumulative number of people (from the end of the corridor to X) aboard the vehicle entering the increment ΔX was computed. At any point along the route at X distance from CBD, the total cost function that affects the stop location consists of the three parts: the operator cost of vehicle currently at X stopping in the next increment ΔX, the cost of users along the route accessing the stop within increment ΔX, and the delay cost for the cumulative transit demand (i.e., the passengers aboard the vehicle) that originated at an area beyond the potential stop in the increment ΔX and the outer end of the corridor. The parts of the function that do not affect stop spacing are left out of the total cost equation because they drop to 0 in the derivatives of the cost function. The partial cost function at any point X along the corridor is

$$TC(Si) = \frac{2cdY}{HM}\int_{X-\Delta X}^{X}\frac{1}{Si}dx + \frac{V_aY}{4G}P\left[Si\int_{X-\Delta X}^{X}dx + V_{iv}d\Delta XY\frac{1}{Si}\int_{X}^{E}dx\right] \quad (9)$$

The partial derivative of Equation 9 with respect to stop spacing is

$$\frac{\partial TC(Si)}{\partial Si} = -\frac{2cdY}{Si^2HM}\Delta X + \frac{V_aY}{4G}P\Delta X + \frac{V_{iv}d\Delta XY}{Si^2}P(E - X) = 0 \quad (10)$$

The optimal stop spacing is

$$Si^* = \left\{\frac{4Gd[2c + V_{iv}HP(E - X)M]}{V_aPHM}\right\}^{1/2} \quad (11)$$

Equation 11 is used to compute the optimal fractional number of stops within each increment i, that is, Ni^*

$$Ni^* = \frac{\Delta X}{Si^*} \quad (12)$$

The total number of stops in the corridor is then obtained by summing incremental stops over all the increments i, namely,

$$N^* = \sum_{i=1}^{E/\Delta x} N^*i \quad (13)$$

The optimal number of stops is used in the next step to derive the optimal route length. After the optimal values of all decision variables are computed, the actual location of a stop is determined using Equation 13 by summing the stop increments on the route in the direction to the CBD. Each time an integer number is reached in the cumulative function of the number of stops, a true stop is established.

Optimal Route Length

The optimal route length is obtained as a result of the tradeoff between operator and user access costs. Intuitively, the route should end at the point at which the supplier marginal costs equals the marginal access cost for users accessing the route from an area beyond the terminus. Access along the route to the stop is omitted from consideration for the optimal number of stops has been determined in the previous step. Thus, the partial cost function is

$$TC(N^*,L) = \frac{2cYL}{VHM} + \frac{V_a}{G}\frac{(E - L)^2}{2}PY \quad (14)$$

Taking the partial derivative of Equation 14 with respect to the route length and setting it equal to 0 yields the following expression for the optimal route length:

$$L^* = E - \frac{2cG}{V_aPHVM} \quad (15)$$

Equations 13 and 14 are used as input for computing the optimal route spacing M^*.

Optimal Route Spacing

The optimal route spacing depends on the magnitude of user access cost via paths perpendicular to the route as well as on the operator cost per route. In Equation 7c the L/S is replaced by N^*, yielding the modified equation that is used within the algorithm:

$$M^* = \left[\frac{8G(L^*c + dN^*)}{V_aPEH^2}\right]^{1/2} \quad (16)$$

Optimal Headway

The optimal values of N^*, L^*, M^* are then input into the modified Equation 7d, yielding the optimal operating headway on the route:

$$H^* = \left[\frac{4c(L^* + VdN^*)}{V_wPEM^*V}\right]^{1/2} \quad (17)$$

NUMERICAL EXAMPLE—RECTANGULAR CORRIDOR WITH UNIFORM PASSENGER DENSITY

The input data for this example are shown in Figure 3. The parameter values were taken from Keeler and Small (*21*) for values of time and from Fisher and Viton (*22*) for costs. The algorithm generated optimal route length, route spacing, operating headway, number of stops, supplier and user cost, and the total cost of the transit system, which are given in Table 2. The table shows several iterations of the algorithm, which shows that it converges quickly toward the optimum solution. Note that the optimal headway of 8.5 min that minimizes the total cost is much smaller than the maximum allowable headway of 12 min that was used as an initial feasible solution. The total cost function is relatively flat near the optimum. This indicates that minor deviations away from the optimum will not increase the cost significantly. It is notable that at the optimum, the costs of user access time, of operating the service, and of waiting time are equal. This optimality condition is similar to the findings reported by Holroyd (*1*), Kocur (*12*), and Tsao and Schonfeld (*13,14*) for their particular models. The optimal route length, route spacing, and stop location are shown in Figure 3. This figure shows that the stop spacing increases along the route in the direction of passenger accumulation toward the CBD. At the outer end of the transit route, the delay cost of operator and passengers already on board is smaller than the access cost of passengers along the route who are trying to board. As access costs outweigh delay costs, more frequent stops are established. As the route approaches the CBD, the number of passengers aboard the vehicles increases so that the delay cost begins to outweigh the access cost to passengers along the route who are trying to board, thus increasing the optimal stop spacings.

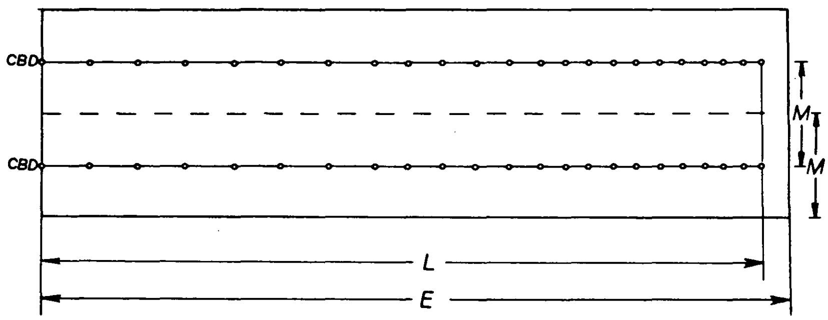
SPECIAL CASES

The optimization approach was also applied to a rectangular corridor with the passenger density decreasing linearly from the CBD and to a wedge-shaped corridor with uniform passenger density. The input data for these cases are the same as for the previous example.

Rectangular Corridor with Linearly Decreasing Passenger Density

To yield the same passenger volume as in the previous example so that the results can be compared, the passenger density of 77.2 passengers per kilometer per hour was assumed

transit corridor length:	8.045 km (5 miles)
transit corridor width:	4.827 km (3 miles)
average transit speed:	16.09 km/hour (10 miles/hour)
average access speed:	4.39 km/hour (2.73 miles/hour)
boarding (or alighting) time:	2 seconds
operator cost:	$30/vehicle-hour
value of access time:	$9/passenger-hour
value of in-vehicle time:	$3/passenger-hour)
value of waiting time:	$9/passenger-hour)
passenger density:	38.6 passengers/km^2-hour (100 passengers/mile^2-hour)
transit vehicle capacity:	50 seats/vehicle
allowable peak load factor:	1.0



o = Stop/Station

1 MILE

Optimal Values:
Route Length L: 7.78 km/route (4.83 miles/route)
Headway H: 8.5 minutes
Spacing M: 1.24 km/route (0.77 miles/route)

FIGURE 3 Optimal transit route configuration for rectangular area with uniform passenger density.

in the linear density function—$P = 77.2(1 - x/E)$. Figure 4 (*top*) shows the optimal transit route configuration. From the figure, it can be seen that the stop spacing is decreasing along the route toward the CBD. This is consistent with the passenger distribution along the route. Because passenger density decreases from the CBD, the passenger transit demand in the outer area is much smaller than it is near the CBD. At a certain distance from the CBD, the stop spacing starts increasing. As the route approaches the CBD, the number of passengers aboard vehicles rises rapidly so that these passengers' delay costs increase faster than the access costs of passengers along the route. As in the previous example the algorithm converges quickly to the optimal solution. A detailed discussion of this case study may be found in work by Spasovic (*16*).

Wedge-Shaped Corridor with Uniform Passenger Density

Figure 4 (*bottom*) shows the optimal transit configuration for the wedge-shaped corridor. In it, the stop spacing increases along the route in the direction of passenger accumulation toward the CBD. As the route approaches the CBD, the number of passengers aboard the vehicle increases so that their delay costs outweigh the access costs of passengers along the route waiting to board the vehicle. In addition, because of the wedge shape of the service area, the number of passengers is decreasing in the direction of the CBD. As in the previous examples, the algorithm converges quickly toward the optimal solution. At the optimum, the total supplier cost (including delay cost) and the user access cost are equal. The user wait costs are about 25 percent lower than either operator or user access cost. However, it should be pointed out that the operating cost (without stop delay) and the user wait cost are equal at the optimum. A detailed discussion of this case study also may be found in work by Spasovic (*16*).

Sensitivity Analysis

The sensitivity analysis is performed to show how changes in the more important exogenous parameters affect the values of the decision variables. The results are presented in the form of elasticities, which are convenient dimensionless measures of sensitivity. Two approaches for performing the sensitivity analysis were used. First, the sensitivity of one transit design element with respect to a particular parameter was examined without reoptimizing the system. This approach provides a very good insight into the relative changes in the dependent element of the transit system if a change in a particular parameter occurs. Second, the sensitivity of the groups of transit design variables with respect to the single parameter has been measured after reoptimizing the system. The elasticities of the design variables—namely, route length, spacing, headway and number of stops with respect to the corridor length, passenger density, transit and access speed, operator cost, and values of riding access and waiting times without and with reoptimization—are presented in Tables 3 and 4. The tables show that, for example, if the passenger density is increased by 10 percent the headway will be reduced by 4.8 percent. This result confirms that headway varies (ap-

TABLE 2 Optimal Cost and Design Variables

Solution No.	I	II	III	IV	V	VI	VII Optimal	VIII
Route Length (km/route)	7.9	7.69	7.8	7.76	7.78	7.77	7.78	7.77
Route Spacing (km/route)	1.609	1.054	1.303	1.197	1.252	1.230	1.241	1.236
Route Density (routes/km)	1.609	0.949	0.767	0.835	0.8	0.8138	0.806	0.768
Headway (minute/vehicle)	12.00	7.52	9.1	8.3	8.6	8.4	8.5	8.5
No. of Stops	24.96	21.20	23.15	22.32	22.71	22.54	22.62	22.59
Operator Cost ($/hr)	441.81	1046.22	709.47	846.3	781.44	810.3	797.13	803.07
Operator Delay Cost ($/hr)	89.25	194.01	135.03	158.58	147.24	152.19	149.88	150.90
Total Operator Cost ($/hr)	531.06	1240.23	844.5	1004.88	928.68	962.49	947.01	953.97
User Access Cost ($/hr)	1240.35	834.51	1013.25	933.3	974.73	959.19	967.44	964.29
User Wait Cost ($/hr)	1350.0	846.6	1024.8	930.3	966.9	947.7	954.9	951.0
Total System Cost ($/hr)	4451.19	4182.27	4172.49	4166.34	4162.92	4163.07	4162.71	4162.77
Fleet Size (vehicles)	17.702	41.341	28.15	33.496	30.956	32.083	31.567	31.799

proximately) with the square root of the passenger density. In addition, in both cases the optimal route length L is elastic (i.e., the absolute value of the elasticity exceeds 1.0) with respect to the corridor length E. The reason for this is that as the length of the corridor E is increased, the length of the area between the terminus and the end of the corridor, $E - L$, is increased very slowly, thus increasing L faster than E. The results of sensitivity analysis for the other two cases may be found in work by Spasovic (*16*).

CONCLUSIONS

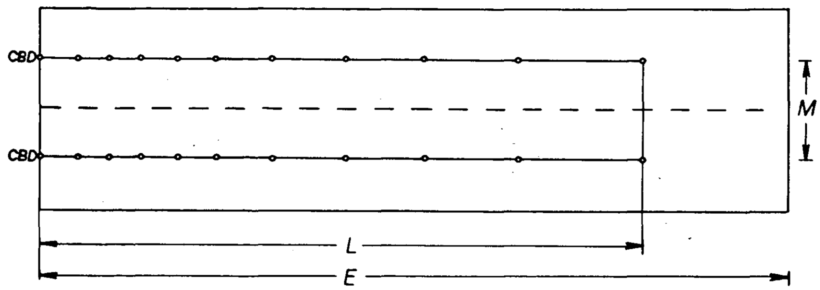
The model developed in this paper provides simple guidelines for optimizing the extent of transit routes and other major operating characteristics. Equations 7a–7d can be used to optimize separately route length, route spacing, headway, and stop spacing. The square root in Equations 7b–7d indicates that optimal solutions are relatively insensitive to changes in system parameters.

The algorithm provides an efficient and accurate method for simultaneously optimizing the decision variables. The results closely confirm that in a system optimized for minimum total cost, the vehicle operating cost, user wait cost, and user access cost should be equal. This finding is similar to those of previous studies (*1,12–14*) for somewhat different transit systems and provides a useful optimality guideline for designing real transit systems.

The total cost function is relatively flat near the optimum. For practical applications, this implies that a near-optimal cost can be attained while fitting the transit network to the particular street network or modifying its operating schedule.

FUTURE RESEARCH

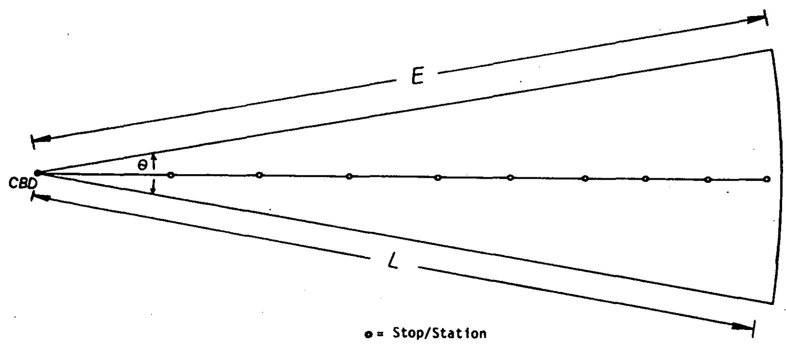
Several simplifying assumptions should be relaxed in future models. More realistic and irregular distributions of demand over space and time should be used. The model should be improved to handle non-CBD trips and access modes other than walking. The cost of transit facilities (e.g., station cost) should be considered in order to make the methodology more applicable in planning fixed guideway modes. Demand elasticity should be explicitly considered in formulating demand as a function of level of service and fare. This will also allow optimization for objectives such as profit, revenues, and welfare.



o = Stop/Station

1 MILE

Optimal Values:
Route Length L: 6.47 km/route (4.02 miles/route)
Headway H: 7.9 minutes
Spacing M: 1.14 km/route (0.71 miles/route)



o = Stop/Station

1 MILE

Optimal Values:
Route Length L: 7.9 km/route (4.91 miles/route)
Headway H: 7.5 minutes
Spacing Θ: 19°19' degrees/route

FIGURE 4 Optimal transit route configuration: *top*, rectangular area with linearly decreasing passenger density; *bottom*, wedge area with uniform passenger density.

TABLE 3 Elasticities of Design Variables with Respect to Various Parameters for Rectangular Area with Uniform Passenger Density, Without Reoptimization

	Design Variables			
	Route Length	Headway	Route Spacing	Number of Stops
Corridor Length	1.0286	- 0.0013	- 0.0010	0.6912
Passenger Density	0.0185	- 0.4807	- 0.4806	0.0625
Transit Speed	0.0185	- 0.4103	- 0.4103	0.0000
Access Speed	- 0.0328	0.0000	0.5052	- 0.5050
Operator Cost	- 0.0328	0.5051	0.5052	- 0.2447
Value of In-Vehicle Time	0.000	0.000	0.0000	- 0.2967
Value of Access Time	0.0185	0.000	- 0.5049	0.5050
Value of Wait Time	0.000	- 0.5050	0.000	0.0000

TABLE 4 Elasticities of Design Variables with Respect to Various Parameters for Rectangular Area with Uniform Passenger Density, with Reoptimization

	Design Variables			
	Route Length	Headway	Route Spacing	Number of Stops
Corridor Length	1.0278	- 0.0076	0.0068	0.7317
Passenger Density	0.0116	- 0.3247	- 0.3258	0.0083
Transit Speed	0.0146	- 0.2742	- 0.2751	- 0.1207
Access Speed	- 0.0282	- 0.3487	- 0.6596	- 0.3892
Operator Cost	- 0.0125	0.3382	0.3379	- 0.1296
Value of In-Vehicle Time	- 0.00005	0.0002	- 0.00003	- 0.2596
Value of Access Time	0.0209	0.3476	- 0.6618	0.3806
Value of Wait Time	- 0.0135	- 0.6819	0.3257	- 0.0289

APPENDIX A
Notation

The following symbols are used in this paper:

c = vehicle operating cost ($/veh-hr)
C_a = total access time cost ($/hr)
C_{iv} = total in-vehicle travel time cost ($/hr)
C_o = total operator cost ($/hr)
C_u = total user time cost ($/hr)
C_w = total waiting time cost ($/hr)
d = average time lost per stop (hr/stop)
E = corridor length (km)
G = average passenger access speed (km/hr)
H = operating headway for a transit route (hr/vehicle)
K = vehicle capacity (seat/vehicle)
L = length of transit route (km)
l = allowable peak hour load factor at CBD
M = lateral route spacing for rectangular area (km/route)
n = number of routes
N = number of stops on route
θ = lateral route spacing for wedge area (degree/route)
P = passenger trip density (passenger/km^2-hr)
S = average stop spacing (km/stop)
TC = total cost of a transit system ($/hr)
V = average transit operating speed (km/hr)
V_a = value of access time ($/passenger-hr)
V_{iv} = value of passenger in-vehicle time ($/passenger-hr)
V_w = value of passenger waiting time ($/passenger-hr)
Y = corridor width (km)

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Ridership Forecasting for Chicago Transit Authority's West Corridor Project

RONALD EASH, KENNETH DALLMEYER, AND RICHARD COOK

The Chicago Transit Authority is reviewing existing West Corridor rail services. A spreadsheet version of the Chicago Area Transportation Study's mode choice model was developed for the project to estimate the impact of service revisions on ridership. Ridership calculations are carried out for Chicago community areas, a level of detail that permits the model to be implemented within a reasonably sized spreadsheet. The spreadsheet's organization is discussed, and procedures to estimate inputs to the mode choice model—access and line-haul characteristics faced by riders—are outlined. This approach is critiqued and contrasted with conventional network-based travel demand models.

The West Corridor project focuses on Chicago Transit Authority (CTA) rail service. Two of the corridor's three rail lines date from the turn of the century and need structural rehabilitation. Total ridership on the west-side lines has declined at a faster rate than CTA rail ridership on the whole (*1*). Operating costs per passenger have escalated because of lost ridership.

A spreadsheet version of the Chicago Area Transportation Study's (CATS's) mode choice model estimates how alternatives to current west-side service affect ridership. Existing and revised characteristics of a service plan are entered into the spreadsheet, and time and cost impacts projected for riders. A mode choice calculation estimates the transit ridership lost or gained. Remaining ridership is then allocated to bus, commuter rail, and west-side rail lines.

MODELING CONSIDERATIONS

Considerations for selecting this approach were as follows:

1. Detailed ridership forecasts. Ridership forecasts were needed to estimate revenue and cost implications of alternative operating plans.
2. Available project resources. Available resources were CTA staff, personal computers, and spreadsheet or data base management software.
3. Previous work. Trip tables were prepared in previous CTA strategic planning (*2*).

PROJECT ZONES

Figure 1 zones were developed from Chicago community areas. Zone 1 is the central area; Zones 2 through 10 are corridor community areas; Zones 11, 12, and 13 cover western suburbs served by CTA; and Zone 14 includes all remaining western suburbs. The balance of the study area is covered by 12 zones arranged in rings and sectors.

Also shown are the Lake Street, Congress, and Douglas rail lines. In addition, there are 12 CTA east-west bus lines and 2 commuter rail lines in the corridor.

ORGANIZATION OF SPREADSHEET

A spreadsheet includes seven sections for one corridor zone's ridership calculations:

1. Zone trips,
2. Existing line-haul and access characteristics,
3. Line-haul and access characteristics for the revised service,
4. Impacts,
5. Automobile-transit mode shift calculations,
6. Transit submode shift calculations, and
7. Summary tables.

Trips

Trip tables include movements from West Corridor origin zones 2 through 14 to all 26 destination zones. Tables were prepared for home to work, work to home, home to nonwork, nonwork to home, and nonhome to nonhome trips.

Work trip tables for automobile, commuter rail, CTA bus, and CTA rail were created from the 1980 census journey to work files (*3*) and factored to 1985. Nonwork tables for CTA modes were tabulated from a 1979 CTA origin-destination survey (*4*). CTA rail trips were further subdivided into Douglas, Congress, Lake Street, and other rail lines using factors from the 1979 survey. One row from each modal table produces the spreadsheet's zone trip table depicted in Figure 2.

One alternative requires 13 (origin zones) × 5 (trip purposes) spreadsheets, but fewer than 65 spreadsheets are usually needed. Origin zones and purposes can be omitted when they contribute little ridership.

Line-Haul and Access Times and Costs

Service characteristics are time in transit vehicles, time outside the vehicle, and fares paid. Out-of-vehicle time has three components: walk time to the first stop or station, half the

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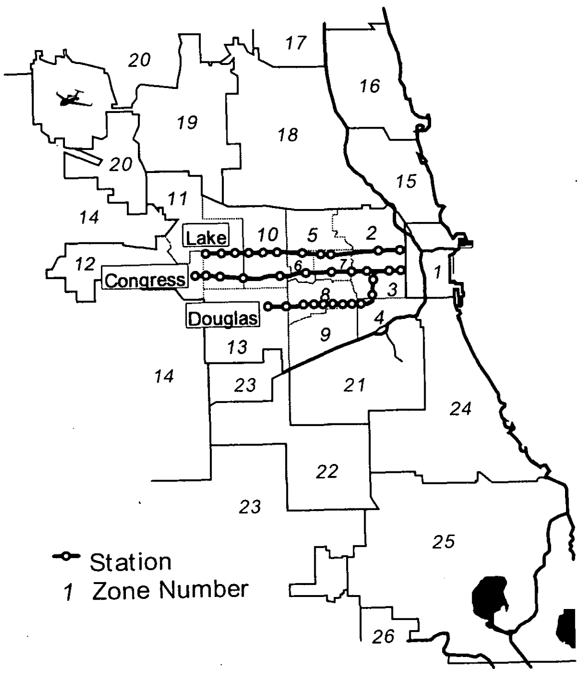

FIGURE 1 West Corridor project zones and rail lines.

headway of the first boarded line, and transfer time, if any, between rail lines. Peak service characteristics are paired with work trips, and nonwork trips, with off-peak characteristics.

The spreadsheet treats rail line-haul and access characteristics separately. Line-haul quantities are measured between stations. Access characteristics are determined by the trip to the station. Bus line-haul and access characteristics are combined, because nearly all CTA bus riders walk to stops. Times and costs of automobile and commuter rail are assumed constant.

Line-Haul Times and Costs

Zone-to-zone line-haul characteristics were measured between pairs of stations. Within the corridor, reference stations were selected on each west-side rail line for each zone. Outside of the corridor, one station was also identified per zone. Rail line-haul times came from CTA Operating Facts (*5*) and

	Destination Zones												
Mode/Line	1	2	3	4	5	6	7	8	...	24	25	26	Total
Auto													
Bus													
Commuter Rail													
Lake Street													
Congress													
Douglas													
Other Rail Lines													
Total													

FIGURE 2 Organization of spreadsheet zone trip table.

crew assignment supervisor guides. Bus line-haul characteristics were measured between street intersections. Interchanges requiring transfers between lines were identified to determine applicable fares and transfer times between zones.

If a rail line is eliminated, line-haul characteristics of the best remaining rail line are substituted. Potentially eliminating the Lake Street line is reproduced by replacing its line-haul characteristics with those of the Congress line.

Access Times and Costs

Access characteristics were estimated by sample trips from a small 1988 CTA home interview survey (*6*) and the 1979 CTA survey.

1. Ten to 20 survey trips are selected for bus and for rail riders on each line serving a zone.
2. Access characteristics for sample trips are determined.
3. Weighted average access characteristics are calculated by line and access mode within a zone.

Access characteristics for proposed services are also estimated by this procedure. Elimination of a station or line means that access characteristics must be adjusted to reflect use of the best alternative station.

Changes in Access Times and Costs

Changes in access characteristics are more complex than line-haul characteristics because riders will often change access modes. An intermediate table keeps track of the access impacts for all combinations of access modes used before and after rail service is altered and the number of survey trips affected. Six table columns—walk to walk, walk to bus, walk to automobile, bus to bus, bus to automobile, and automobile to automobile—account for all before and after access modes.

Impacts on Line-Haul and Access Times and Costs

Two tables summarize impacts of a service alternative, one for the transit-automobile pivot-point mode shift calculation and one for the transit submode allocation. Since automobile characteristics remain unchanged, transit-automobile impacts are only the changed transit characteristics.

Each line's transit impacts are measured relative to all other services for the transit submode pivot-point calculation. When the Lake Street's impacts are determined, they are tabulated for the Lake Street versus bus, commuter rail, Douglas, Congress, and noncorridor rail lines. These pairings allow for shifts in ridership among corridor transit services.

Pivot-Point Mode Shift Calculations

Two tables estimate the transit-automobile and submode shifts in mode choice. The transit-automobile pivot-point table is organized by transit mode and rail line, whereas the transit

TABLE 1 CATS Mode Choice Model Coefficients

Variable	Work Trips: CBD Destination	Work Trips: Non-CBD Destination	Non-Work Trips: CBD Destination	Non-Work Trips: Non-CBD Destination
Transit-Auto Mode Choice				
In-Vehicle Time	0.0159	0.0186	0.0114	0.0114
Out-of Vehicle Time:				
First Headway	0.0173	0.0811	0.0610	0.0610
Transfer Time	0.0290	0.0399	0.0589	0.0589
Walk Time	0.0468	0.0584	0.0663	0.0663
Fare/Cost	0.0085	0.0072	0.0329	0.0329
Transit Submode Choice				
Total Time	0.0220	0.0119	0.0207	0.0127
Total Fare/Cost	0.0175	0.0200	0.0347	0.0493

submode pivot-point table includes paired transit modes and rail lines.

The following equation performs the pivot-point calculation:

$$DMSm = MSm * (1 - MSm) * DCm * Fm,C \quad (1)$$

where

$DMSm$ = change in mode share for mode m;
DCm = impact on service characteristic C for mode m; and
Fm,C = coefficient in mode choice model that weights service characteristic C for mode m.

Table 1 gives the coefficients for transit-automobile mode choice and transit submode choice from the CATS model (7).

FINAL COMMENTS

The spreadsheet model estimated ridership after lengthening headways on the Lake Street line to accommodate a new Southwest rail line. The project is now examining ridership effects from potential elimination of either the Douglas or Lake Street line. The model produces reasonable results when a line is eliminated. Some ridership is shifted to competing automobile, commuter rail, or bus, but most is allocated to the remaining corridor rail lines.

Experience with the model confirms the importance of transit access. Line-haul characteristics often vary only slightly between alternatives. When a line is eliminated, the line-haul characteristics of the substitute line are sometimes superior, but access characteristics are typically worse.

Each spreadsheet is customized according to the available transit services, the interchanges in the trip table, and the access calculations for eliminated lines. Although custom spreadsheets are cumbersome, they force the analyst to understand the spreadsheet calculations.

The spreadsheet remains manageable because the project deals with one corridor and evaluates limited network changes. System planning involves more extensive alternatives, which must be addressed by network-based models. The choice of either analysis method should be driven by the nature of the planning problem.

ACKNOWLEDGMENT

The authors would like to thank Darwin Stuart of the CTA for his support during the project.

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Cost-Effectiveness of Direct Mail Marketing to New Residents

CAROL PEDERSEN AMBRUSO

In January 1989 the Tri-County Metropolitan Transportation District of Oregon (Tri-Met) began offering a promotional packet to new residents in selected ZIP codes within the Tri-Met service district. The primary objective of the program was to increase ridership by attracting new riders and retaining existing riders after they move. In February 1991 Tri-Met launched a year-long study to determine how often and for what period of time new riders who received a direct mail promotion continued to ride Tri-Met. The study found that after a year, 64 percent of these new riders continued to ride, making 21 trips a month on average. The length of time that a person stays with the Tri-Met system appears to be correlated to the number of trips they made on Tri-Met when they first started riding: the more trips respondents made initially, the more likely they were to continue riding. The promotion is cost-effective; the payback period is less than 3 months, including all development, production, mailing, and lost revenue costs. Respondents generally pay their fares using the most economical method for the number of trips that they plan to take in a given month with two exceptions: those who always pay cash (about 10 percent) and those in lower-income brackets who make more than 30 trips a month. Targeted direct mail promotions such as the new residents promotion should be continued because they appear to be effective in terms of both attracting and retaining riders at a relatively low cost to the agency.

In January 1989 the Tri-County Metropolitan Transportation District of Oregon (Tri-Met) began offering a promotional packet to new residents in selected ZIP codes in the Tri-Met service district. New residents include newcomers to the area as well as those who changed residences within the Tri-Met service district. The primary objective of the program was to increase ridership by attracting new riders and retaining existing riders after they move.

Each packet contained a letter outlining the benefits of riding transit, a packet of information about riding Tri-Met, and a response coupon that could be redeemed for 10 free tickets. An individual identification number and a short survey were printed on the response coupon. The survey asked respondents how often they rode transit before and after moving.

A research study analyzing results of the first 2 months of the promotion found that 17 percent of respondents who were nonriders rode Tri-Met at least seven times a month after the promotion (*1*). In fact, 5 percent of all nonriders began riding Tri-Met 30 or more times a month after receiving the promotion.

In February 1991 Tri-Met launched a year-long study to determine how often and for what period of time new residents who starting riding after receiving the direct mail promotion continued to ride Tri-Met. The study was also designed to examine (a) why respondents began riding Tri-Met; (b) the changes, if any, in the respondents' riding frequency; (c) the changes, if any, in fare payment method over 1 year; and (d) if applicable, the reasons respondents stopped riding Tri-Met.

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SAMPLE DESIGN AND SELECTION

Data from the coupon survey contained in the original direct mail packet were used as the basis for selecting a sample for this cost-effectiveness study. Using the unique identification numbers included on the coupons, Tri-Met obtained the names and addresses of new resident respondents who made fewer than two transit trips a month before moving and two or more transit trips a month after moving. This selection method yielded an initial sample size of 1,045.

Names and addresses of those selected were sent to US West Communications to obtain telephone numbers. Of the 1,045 names and addresses submitted, US West was able to find published telephone numbers for 528 persons. The remaining 517 were surveyed by mail and asked to provide their telephone number for future contacts.

The study design called for these new riders to be interviewed once each quarter to determine whether they were still riding, how often they rode, and how they paid their fare. Each quarter respondents were eliminated from further study if they failed to respond to the previous survey or if they had stopped riding Tri-Met within the past 3 months and had no plans to resume riding within the next quarter. Table 1 displays the sample sizes and response rates for each round of interviewing.

RIDING FREQUENCY AND ATTRITION

February 1991

The first round of interviewing was conducted in February 1991, approximately 3 months after respondents to the promotion received their direct mail packets. Of the 1,045 persons selected for the study, initial interviews were completed with 578, a response rate of 55 percent.

Attrition rates are calculated on the basis of responses to the question, "How many trips do you currently make on a Tri-Met bus or MAX each month? Please count each direction as one trip." Respondents who said that they made no transit

TABLE 1 Sample Sizes and Response Rates per Quarter

	Feb.	May	Sept.	Dec.
Sample Size				
Telephone	528	432[a]	332[b]	239
Mail	517	60	19	0
TOTAL	**1,045**	**492**	**352**	**239**
Response Rates %				
Telephone	71	81	78	81
Mail	38	50	63	---
COMBINED	**55**	**77**	**73**	**81**

[a] Includes 124 respondents who provided a telephone number from the previous mail survey.

[b] Includes 11 respondents who provided a telephone number from the previous mail survey.

trips and had no plans to resume using transit in the next 3 months were included in the attrition calculation. Respondents who planned to resume transit use but failed to do so were included in the attrition calculation after the next round of interviewing.

The overall attrition rate after the first round of surveying was 7 percent, which means that 7 percent of those who responded to the survey stopped riding within 3 months of receiving the promotion. These respondents were excluded from subsequent surveys. The mean number of trips per month among those who continued to ride was 21.5.

May 1991

After eliminating nonriders and those who provided no transit trip information in the first round of surveying, the sample for the second round, conducted in May, was 492. A total of 378 interviews were completed, for a response rate of 77 percent.

The attrition between the February and May surveys was 12 percent—that is, 12 percent of those surveyed in May stopped riding transit between 3 and 6 months after receiving the promotion.

Cumulative attrition rates were calculated on the basis of the original sample of 1,045 with the assumption that those who failed to respond to the surveys stopped riding transit at the same rate as those who did respond. Thus, the cumulative attrition rate at the end of May is 18 percent, calculated as follows:

1,045 (initial sample size) * 0.07 (February attrition) = 73

1,045 − 73 = 972 * 0.12 (May attrition) = 117

117 + 73 = 190/1,045 = 18 percent

September 1991

After eliminating nonriders and those who provided no transit trip information in May, the sample size for the third survey conducted in September was 352. A total of 258 interviews were completed, for a response rate of 73 percent.

The attrition between the May survey and the September survey was 15 percent. The cumulative attrition rate for the initial sample (n = 1,045) was calculated to be 30 percent, representing the total number of new riders who stopped using transit within 9 months of receiving the promotion.

1,045 (initial sample size) * 0.07 (February attrition) = 73

1,045 − 73 = 972 * 0.12 (May attrition) = 117

972 − 117 = 855 * 0.15 (September attrition) = 128

117 + 73 + 128 = 318/1,045 = 30 percent

December 1991

After eliminating nonriders and those who provided no transit trip information in the September survey, the sample for the December study was 239. A total of 194 interviews were completed, for a response rate of 81 percent.

The attrition between the September and December surveys is 8 percent. The cumulative attrition rate 1 year after receipt of the direct mail promotion was calculated to be 36 percent.

1,045 (initial sample size) * 0.07 (February attrition) = 73

1,045 − 73 = 972 * 0.12 (May attrition) = 117

972 − 117 = 855 * 0.15 (September attrition) = 128

855 − 128 = 727 * 0.08 (December attrition) = 58

117 + 73 + 128 + 58 = 376/1,045 = 36 percent

CHANGES IN RIDING FREQUENCY

A comparison of transit trip frequency for each quarter of the survey project shows that riders are fairly stable in terms of the number of trips they make each month. Table 2 shows the percentage of respondents in each transit trip category over the course of the study. Figure 1 displays this same information graphically to better illustrate ridership trends.

FARE PAYMENT

As part of this study, respondents who were still riding Tri-Met at the time each survey was conducted were asked how they pay their fare to track how fare payment methods change over time. The first survey, in February, showed the following results:

Payment Method	*Percentage*
Cash	33
Cash-ticket combination	13
Ticket	35
Monthly pass	19

The mean number of transit trips per month at this time was 21.5.

The Tri-Met fare structure is designed to encourage ridership by providing volume discounts. For example, buying a book of 10 all-zone tickets saves $1.00 over the regular cash fare for 10 all-zone rides. For purposes of this paper, respondents were divided into three groups on the basis of the number of transit trips that they make each month. For those making between 1 and 10 trips per month, cash or ticket fares are the most economical means of payment. Tickets are most economical for those making 11 to 31 trips a month, and passes are most economical for those who make 32 trips or more. Although tickets are always a more economical option than cash, the savings for those making fewer than 10 trips per month is insignificant.

Table 3 presents the method that respondents used to pay their fares by the number of trips they made per month at the time each survey was conducted. The most cost-effective payment method in each category is shown in italics. The majority of respondents selected the most economical fare payment method except, perhaps, initially when a greater percentage paid cash. This finding implies that respondents were uncertain of their level of commitment to transit when they first began riding, but as they became more comfortable, they quickly began to use the most economical method of payment.

For example, only 47 percent of respondents who made 32 or more transit trips in February bought a monthly pass. The rest paid with cash, tickets, or both. In May, 65 percent of those making 32 or more trips per month bought a pass. Many respondents in this trip category who did not buy a pass are in the lower-income brackets, suggesting that they may not be able to afford the full pass price at the beginning of the month.

Some respondents simply preferred cash. Ten percent of those who participated throughout the entire study always paid with cash regardless of the number of trips they made each month.

Respondents in the 11–31 trips category shifted away from cash toward tickets and monthly passes between February and September. There is a shift among respondents in this group from passes back toward tickets and cash in December. This finding probably reflects an expectation of diminished use during the holiday season. The mean number of transit trips per month did decline slightly between September and December.

A fare survey of the entire Tri-Met system conducted in October 1991 showed that 35 percent of all trips are paid with cash, 15 percent with tickets, and 50 percent with a monthly pass. This study found a somewhat different pattern of fare payment when compared with the systemwide study. As given in Table 4, the use of cash among participants in the direct mail study is significantly less than cash use in the entire Tri-Met system. Moreover, cash use diminished over time while pass use increased from 29 percent after the first round of surveys in February to become comparable with the system average of 50 percent.

TABLE 2 Comparison of Transit Trip Frequency

	Percent of Respondents			
Transit Trips Per Month	**Feb.**	**May**	**Sept.**	**Dec.**
0	7	12	15	8
1 to 6	28	25	27	35
7 to 12	14	15	14	11
13 to 29	20	17	13	14
30 or More	31	31	31	32
TOTAL	**100**	**100**	**100**	**100**
Mean	21.5	22.4	21.9	21.3

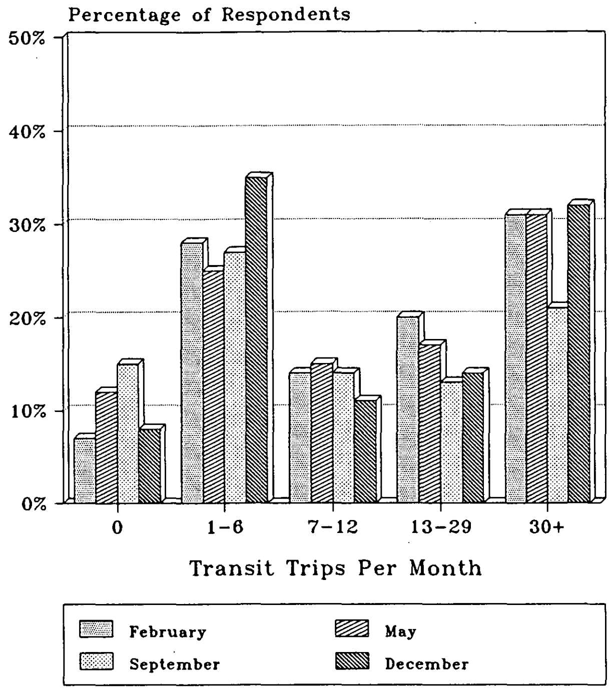


FIGURE 1 Comparison of transit trip frequency.

There are several possible explanations for this finding. The first is that persons making less than one trip per month were dropped from the direct mail study. Systemwide, a number of trips by these very infrequent riders are made every day. These riders generally pay a cash fare.

Trips by very infrequent riders are not sufficient to explain the entire difference between systemwide cash fares and direct mail study cash fares. It is possible that the research design skews results because those most likely to pay with cash were dropped from further study. Another possibility is that those who typically pay with cash live in areas other than those targeted by the promotion. This theory seems unlikely since the promotion primarily targets the inner city, where residents have many transit options and frequent service.

The most likely explanation for the disparity in fare payment methods is that the promotion provided tickets for respondents to use as well as specific information about fares: how much they cost, the types of fares available, where to purchase tickets and passes, and so on. This information, coupled with the experience of using the free tickets provided in the original promotion, enabled respondents to make educated decisions about the most cost-effective fare payment method for their situation.

PROMOTION PAYBACK PERIOD

A 1989 study of the promotion to new residents found the total cost per person on the mailing list to be $2.50 and the total cost for each new rider or rider retained to be $29.13 (*1*). These costs included promotion development and production costs prorated over the first 6 months of the program, monthly mailing costs, and lost revenue from tickets given to existing riders. Updating these numbers to reflect 1992 fares

TABLE 3 Fare Payment Method by Trips per Month

Month/Payment Method	Transit Trips Per Month %		
	1-10	11-31	32+
FEBRUARY			
Cash	<u>48</u>	28	17
Cash/Ticket Combination	15	16	7
Tickets	37	<u>40</u>	29
Monthly Pass	1	16	<u>47</u>
MAY			
Cash	<u>42</u>	22	11
Cash/Ticket Combination	6	7	2
Tickets	47	<u>48</u>	22
Monthly Pass	5	22	<u>65</u>
SEPTEMBER			
Cash	<u>43</u>	26	10
Cash/Ticket Combination	6	2	4
Tickets	48	<u>44</u>	22
Monthly Pass	3	26	<u>64</u>
DECEMBER			
Cash	<u>51</u>	28	5
Cash/Ticket Combination	1	6	4
Tickets	48	<u>50</u>	24
Monthly Pass	0	17	<u>66</u>

TABLE 4 Comparison of Fare Payment Methods Systemwide with Direct Mail Study Respondents

	Cash	Cash/Ticket Combination	Tickets	Monthly Pass
System-wide Survey %				
(October 1991)	35	N/A	15	50
Direct Mail Study %				
February 1991	19	9	44	29
May 1991	18	4	29	50
September 1991	17	4	30	50
December 1991	14	4	32	50

brings the cost per person on the mailing list to $2.60 and the cost per new rider attracted or rider retained to $30.15.

Tri-Met mails approximately 5,000 promotional packets to new residents each month. The average response rate is 32 percent, of which 8.6 percent are new riders or riders retained at the same or higher level.

The monthly cost of the promotion and the payback period can be calculated using the assumptions that 64 percent of new riders attracted continue to ride for at least 1 full year, and that new riders make an average of 21 transit trips each month at the average cash fare of $1.05/trip.

Incoming Revenue Per Month

Using the values given earlier, the following equations calculate the incoming revenue per month:

5,000 new residents * 0.086 new riders * 0.64 still riding = 275

275 * 21 trips per month * $1.05 = $6,063.75

Monthly Cost to Tri-Met

Tri-Met spends $13,000 on a month's mailings to 5,000 residents:

5,000 new residents * $2.60 per person on mailing list

= $13,000

Payback Period

According to the survey data, Tri-Met will recoup its costs in 2.14 months after mailing the promotion:

$13,000/$6,063.75 = 2.14 months

In reality, Tri-Met could recover the promotional costs much quicker given that attrition in the first quarter was only 7 percent compared with 36 percent at the end of an entire year. When calculated on the basis of 7 percent attrition, the payback period is approximately 1.5 months.

Conversely, the payback could be somewhat longer if those who dropped out of the study stopped riding in proportionally greater amounts than those who remained in the study. It is possible that because study participants knew Tri-Met would contact them quarterly, they remained riders longer than they might have otherwise.

DEMOGRAPHIC CHARACTERISTICS

The initial survey conducted in February collected demographic characteristics of all respondents. As Table 5 indicates, substantially more women participated in the study than men and most study participants had an annual household income of less than $50,000.

Respondents who stopped riding generally rode Tri-Met less often initially, traveled longer distances, paid with cash, and usually went to downtown Portland when they did ride. By comparison, respondents who continued to ride were more likely to pay with tickets or a monthly pass, travel in two zones, and use transit to get to places other than downtown Portland.

TRIP PURPOSE

Each quarter respondents who were still riding Tri-Met were asked what their primary trip purpose was. For the most part, these did not change through the course of the study. As shown in Figure 2, work remained the primary purpose throughout, hovering at about 50 percent. This finding suggests that although work trips are Tri-Met's primary market, a good secondary market may be discretionary trips for shopping and personal business.

The December survey showed a somewhat different distribution of transit trip purposes than the previous surveys. The proportion of work and shopping trips decreased while there was a steady increase in trips for visiting and recreation. These differences are probably due to the holiday season, when people are more likely to use their cars to run errands (such as buying Christmas gifts) on their way home or to take time off to spend with visiting friends and relatives.

SATISFACTION WITH TRI-MET

Respondents to the study were overwhelmingly positive about the agency. When asked "Overall, do you feel Tri-Met is doing an excellent, good, fair, or poor job?" 95 percent said either good or excellent. This finding was consistent throughout the study. Even respondents who stopped riding retained their positive perspective about the agency (Figure 3). Not surprisingly, those who continue to ride Tri-Met have the most positive opinion concerning the agency.

CONCLUSIONS

The cumulative attrition over the course of 1 year was 36 percent. In other words, 64 percent of the new riders attracted through the new residents promotion continued to ride Tri-Met more than 1 year after receiving the packet.

A comparison of transit trip frequency between the February and September surveys shows a fairly stable proportion of riders who make between 7 and 12 trips per month and those who make more than 30 trips per month. December survey results show slightly more fluctuation, particularly in the categories of 2 to 6 and 30-plus trips per month. This fluctuation may be an anomaly due to the holiday season.

When asked why they started riding Tri-Met, respondents to the February survey most often mentioned that they encountered convenience and parking problems, that they live near the route, or that it is their only means of transportation.

Several differences exist between respondents who quit riding and those who continue to ride. For example, the more

TABLE 5 Demographic Characteristics of Respondents

	All Respondents % (n=578)	Respondents Who Quit Riding % (n=110)	Respondents Who Still Ride % (n=205)
AGE			
Under 16	2	1	3
16 to 18	1	0	1
19 to 24	16	14	15
25 to 34	35	38	32
35 to 44	30	32	33
45 to 54	7	8	7
55 to 64	4	2	4
65 and Older	6	6	6
INCOME			
Under $10,000	13	14	11
$10,000 to $19,999	25	20	25
$20,000 to $29,999	26	28	24
$30,000 to $39,999	14	16	16
$40,000 to $49,999	11	8	12
$50,000 to $74,999	8	7	8
$75,000 and Above	4	8	4
GENDER			
Male	43	39	43
Female	57	61	57
LENGTH OF RESIDENCE			
Less Than 6 Months	33	37	34
6 Months to 1 Year	56	52	55
1 or More Years	11	12	12
TRANSIT TRIPS PER MONTH AFTER MOVING			
2 to 6	33	39	28
7 to 12	17	17	18
13 to 29	21	18	22
30 or More	28	26	32
USUAL TRANSIT DESTINATION			
Downtown Portland	68	80	73
Somewhere Else in System	14	15	11
About Half & Half	18	5	16

(continued on next page)

TABLE 5 *(continued)*

	All Respondents % (n=578)	Respondents Who Quit Riding % (n=110)	Respondents Who Still Ride % (n=205)
FARE ZONES TRAVELLED			
One	17	15	19
Two	51	50	49
All Zones	29	35	27
Don't Know	3	0	5
ORIGINAL FARE PAYMENT			
Cash	34	48	28
Cash/Ticket Combination	13	11	10
Tickets	34	30	36
Pass	19	11	27

transit trips respondents made when they first started riding, the longer they stayed with the system (Figure 4).

A significantly higher percentage of those who quit riding paid their transit fare with cash rather than tickets or a monthly pass. This finding is not surprising, given that 51 percent of these respondents were making six or fewer transit trips per month before they stopped riding.

When asked why they stopped riding, respondents most often mentioned that there was no need to ride, that they had bought a car, that it was inconvenient, or that they needed their car for work. These reasons are consistent with findings from other Tri-Met research studies.

Respondents generally chose the most economical means of fare payment after the initial period, when a greater per-

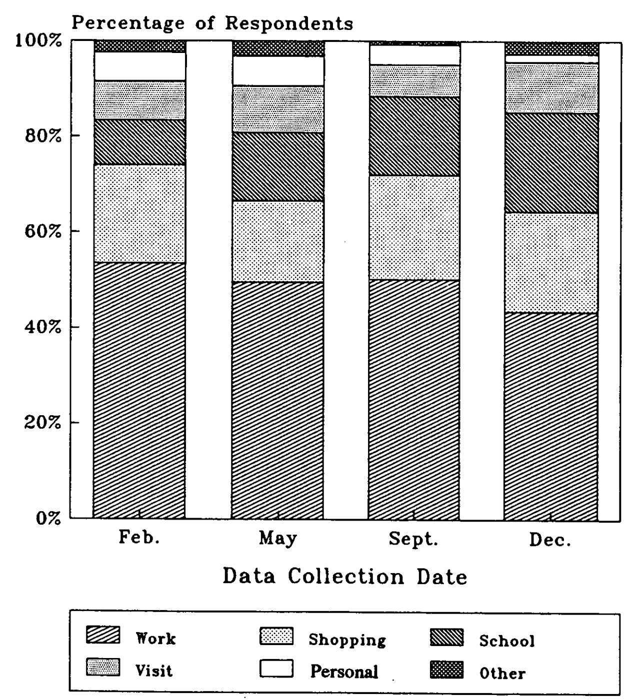
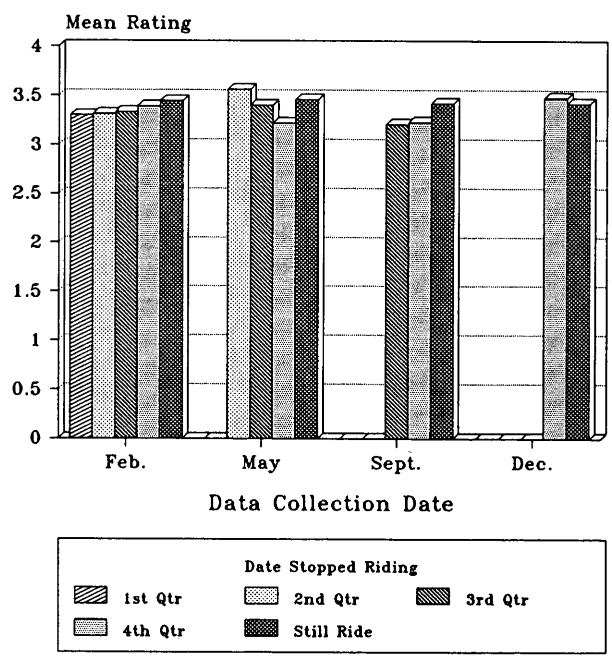


FIGURE 2 Transit trip purpose over time.



Rating scale: 4 = Excellent, 1 = Poor

FIGURE 3 Satisfaction with Tri-Met by date that respondents stopped riding.

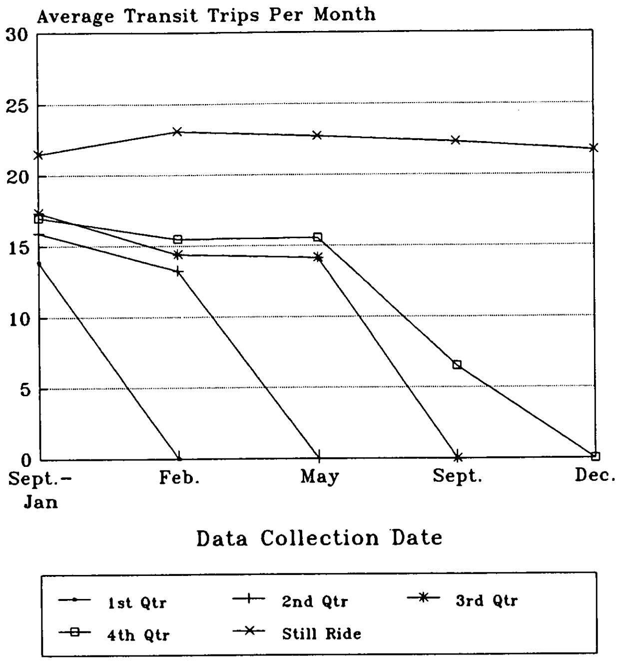


FIGURE 4 Average transit trips per month by date that respondents stopped riding.

centage paid with cash. Exceptions to this rule include the 10 percent who paid with cash throughout the study regardless of the number of trips they made and riders in lower-income brackets. This latter group may have found it easier to pay cash or buy tickets as needed rather than pay the lump sum pass price at the beginning of the month.

Women were more likely to stop riding than men, as were respondents between 25 and 34 years old. Their reasons for stopping did not differ significantly from those of other respondents who quit riding.

Results of this year-long study support the new residents promotion specifically, and direct mail in general as an effective method to recruit new transit riders. The promotion appears to cost-effective given the number of new riders attracted and the short payback period.

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Marketing Theory and Urban Transportation Policy

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A popular theme in urban transportation policy is transportation demand management, or TDM. This policy is in response to years of trying to solve urban travel problems by increasing the supply (e.g., roads) to meet an ever-accelerating demand. As evidenced by the congestion and pollution problems in today's cities, the "supply" policy is not working. TDM focuses on managing and changing travel demand patterns. Increasing the use of mass transit, encouraging housing selection that is closer to work, making it easier to work at home on a personal computer, facilitating vanpools, and developing electronic shopping options are all TDM strategies. TDM, if anything, involves changing consumer behavior in regard to travel and travel-related choices. Three conceptual and theoretical perspectives in marketing are outlined (services marketing, cultural aspects of consumption, and reinforcement theory), and suggestions are made for significantly enhancing this task.

The intent of urban transportation policy in the United States has changed significantly during the past century. Initially, policy was focused on providing for both the mode of choice and mobility levels desired. Such a position led to economic and construction decisions that favored the private automobile. This orientation lasted until the energy shortfalls of the 1970s. In these years, policy was modified to conserve fuel. Curtailed speed limits, investments in mass transit systems, creation of federal programs and funds to support paratransit (car- and vanpools), the designation of high-occupancy vehicle (HOV) lanes, and the development of requirements for vehicle miles per gallon (CAFE) were the result.

As the 1980s began and the fuel shortages lessened, policy once again favored the private automobile, although in a different way. It did not favor the car in the central city, and the road infrastructure was not changed (i.e., there was not a new emphasis on urban road building). Policy, however, did not favor the funding of mass transit, paratransit, and intercity rail efforts. Policy developed in areas other than transportation that directly or indirectly encouraged automobile use. For example, tax policy stimulated real estate development that in large part focused on the available land: the suburbs. This fast and sprawling growth could, for the most part, be served only by private automobile. Additional favoritism was given to the automobile industry by endeavors such as the loan to the Chrysler Corporation and the general climate of the Reagan administration of reducing barriers to the private sector and encouraging economic development.

These policies were in effect at a time when the large "bubble" of the population in the United States, the baby boomers, were forming families. They had a great need for expanded and affordable housing and more transportation because of dual careers and sprawled residential and office development. The combination of the direct and indirect urban transportation policies of the 1980s paired with the changing demographic character of the population led to a situation at the start of the 1990s in which congestion levels on many of the roads of major metropolitan areas in the United States were intolerable.

Because of the overriding concern over congestion (and its impact on economic issues, quality of life, and other environmental concerns), a policy thrust evolved for the 1990s that is characterized by the phrase transportation demand management, or TDM (*1*). Historically, shortfalls in transportation supply-demand functions were met by altering the supply: more cars, roads, bridges, and parking lots were built, for example. But today, many urban policy makers realize that they cannot continue to meet demand by manipulating supply; demand must be managed.

It is the premise of this paper that marketing theory offers an excellent perspective from which to conceptualize and refine TDM policy and to develop implementation programs. By its definition, TDM is a management approach to demand modulation. If anything, marketing is a field that deals with demand issues. Furthermore, TDM implies a focus on consumer behavior. Certainly this is another well-known domain of marketing. Finally, TDM commonly involves changes in what is traditionally called the marketing mix: the service (or product), pricing, distribution, and promotion. The links between marketing and TDM are obvious. The bulk of this paper will attempt to illustrate how three theories in marketing have the potential to contribute significantly to urban transportation policy and to the task of TDM.

THREE THEORETICAL MARKETING PERSPECTIVES AND THEIR CONTRIBUTION TO URBAN TRANSPORTATION POLICY

Three domains of marketing theory have been chosen to address urban transportation policy and TDM: services marketing, the cultural aspects of consumption, and reinforcement theory. Other areas of marketing theory are relevant, but as will be apparent in the following, these three are particularly salient to the urban transportation context. An exhaustive review of the individual significance of these three areas to urban transportation policy and practice is not possible in the context of this paper. A broad approach is taken here simply to introduce their respective

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contributions, and it is left to further endeavors to explore more fully the relevance of these theoretical perspectives to urban transportation.

Services Marketing

A growing and substantive body of theory and empirical findings is developing in services marketing. Another indicator of the growth of this area is the creation of services marketing courses at many universities and the development of services marketing texts (*2,3*). To date, this literature has had little application to transportation policy and issues. In the context of urban transportation, a services marketing approach is appropriate because many urban travel modes could be characterized more as a service than a product [see elsewhere (*4*) for service definitions]. Taxis, van- and carpools, and mass transit certainly fit this definition. HOV lanes, roads and bridges in general, parking garages, and pedestrian and bicycle facilities are certainly "equipment-intensive," but consumers do not buy them—they use them. Finally, the private automobile, in large part, is both a service and a product—a product that is purchased as a result of the decision-making processes used in goods selection, but simultaneously a service that is also judged in much the same way as many other services.

Once it is agreed that urban transportation systems are for the most part services, what can the services marketing literature tell us about urban transportation policy in general and TDM in particular? Of the growing literature on services marketing, some of the issues more relevant to urban transportation policy will be discussed briefly.

First, if a goal is to change demand for mass transit, for example, it must be kept in mind that such a service has many intangible elements in contrast to many products (*5*). As such, the services literature [e.g., the work by Berry (*5*)] suggests that marketing efforts should focus on making the offering tangible. Marketing emphasis might be placed on the physical and tangible aspects of public transportation such as the waiting areas (bus stops and subway stations) and the seats in the vehicles and not on efforts that focus on intangibles such as the ease of the trip and its convenience.

Position in the marketplace is very important for all product and service companies. It is probably more critical to service companies because of the intangibility of their offerings. Because it is harder for many consumers to conceptualize or fully understand a service, it is particularly important for the service provider to clarify, as much as possible, the service by careful and explicit positioning (*2*). The lack of a clear position is certainly a problem for many mass transit systems in the United States. When many of the private systems failed in the 1950s and 1960s (*6*), the major rationale for the public purchase of them was to provide urban transportation for those without cars (the young, the handicapped, the poor, and the elderly). Yet in certain cities or for certain commuting routes, the clientele is upper middle class. This ambiguity in market position creates a problem when the task of the 1990s is to attract more car-driving commuters to mass transit because of congestion.

The services literature also points out that in many cases production and consumption of a service is simultaneous (*2*). For example, a taxi ride is produced and consumed at the same time. This leads to a situation in which quality is hard to control. Inferior products on an assembly line can be eliminated or fixed before the customer comes into contact with them. The provider of a service and the customer often learn that a service is inferior only after it is delivered. This is true in many urban travel situations. Commuting to work on an urban expressway can result in an enjoyable or a disastrous experience that can be categorized only after the event. Services marketing perspectives suggest that the way to deal with this lack of "quality assurance" is to emphasize the training and consistency of the service personnel (e.g., bus drivers) and to develop early warning systems for consumers that advise them of decays in service quality (e.g., the radio station traffic advisory systems in most major cities).

A third perspective put forth by services marketing literature that is relevant to urban transportation policy and TDM focuses on inventory management. A product-oriented business can protect itself against problems of supply shortfall during periods of high demand by having a backup inventory. In many services, however, an inventory is impossible. It is difficult to store extra road capacity on the shelf or spare subways and crews or taxis and drivers. Even if they can be held in abeyance, it is very expensive to do so, especially when they are used only for a relatively short period of time during peak hours. If the spare capacity is not used often (or ever), it is very costly. In contrast, extra products held on inventory are eventually sold and thus do not incur significant financial loss.

Thus, in a service business, where excess capacity is very expensive, an emphasis on demand management is appropriate (*7*). It is logical, for example, to try to get consumers to use highway and mass transit facilities during the off-peak hours rather than building extra capacity for the peak. Although they have not been very successful, attempts have been made to shift the peak of transit use through pricing strategies. Little has been tried in regard to pricing manipulations for highway demand management. Strategies have focused on getting employers to shift their work days (e.g., flex time and staggered work hours). Other than pricing, most of the marketing suggestions for shifting peak demand revolve around communication techniques (public information, publicity, and advertising).

The services literature suggests another perspective, which involves the inventorying of demand (*2*). In other words, save demand until there is excess capacity. Airlines do this by establishing a reservation system. Public transit does it by storing the demand in waiting lines. It might be interesting to inventory demand overtly for other urban transportation systems by establishing a reservation system for road use or parking facilities, for example.

In many urban transportation systems, another services marketing perspective is particularly important. For many services, part of the service includes the other customers receiving that service. This is particularly true of restaurants, sporting events, and certainly mass transit. The provider of transit service can provide comfortable seats in an on-time and clean vehicle, but they have little control over the nature of the customers sharing the ride. The issue of customer mix is dealt with in other situations by dress codes, first- and second-class service (and appropriate pricing), physical barriers, advance notification as to the type of clientele desired, and other techniques. The private automobile is the ultimate means of controlling the customer mix in the urban transportation system. It might behoove other modes of urban travel to consider how they might manage their customer mix so that their service is more appealing. Different classes of service with differential pricing, clear distinctions between the types of service offered, and appropriate physical separation between purchasers of different levels of service might be considered for public transportation.

Zeithmal has pointed out that services are often evaluated differently than products (*8*). Often services cannot be judged until after they are experienced or only by the testimonials of others, whereas many products can be judged before their use through observation. The different ways of gaining information about a service yield evaluation processes for services that are different than those for products. Of Zeithmal's 11 hypotheses about service evaluation, 5 are particularly relevant to urban transportation policy. They are listed here and followed by remarks on their implications to policy and TDM strategies:

- *Consumers seek and rely more on information from personal sources than from nonperson sources when evaluating services before purchase.* This hypothesis is strongly supported by the popularity of telephone information systems for mass transit and by the high use of vehicle operators as information sources. If personal information sources are so popular for urban transportation, they should be enhanced and even include the formalization of using current customers as information sources.
- *Consumers use price and physical facilities as the major cues to service quality.* This hypothesis certainly causes problems for mass transit. Prices are typically held low so that transportation-deprived segments of the population can use the service and the physical facilities are at best spartan, and certainly not often clean. If other market positions and segments are desirable for mass transit, the prices and facilities must yield the appropriate cues to these potential customers. This hypothesis might be expanded to include service personnel as indicators of service quality. Other writers note the importance of the service delivery personnel in customer relations (*2*). These people are not simply in the "factory" producing the service, but a factory that is highly visible to the consumer.
- *The consumer's evoked set of alternatives is smaller with services than with products.* A typical solution to an urban dweller's travel problems is to buy another car. Little thought is given to alternatives such as mass transit, working at home, relocating one's residence, and so forth. It is the task of TDM marketing strategies to clearly inform consumers of their travel options.
- *For many nonprofessional services, the consumer's evoked set frequently includes self-provision of the service.* The option of driving one's own car is an urban travel choice easily made. Marketing efforts must clearly communicate the consequences of various travel options to the travel consumer so that the most obvious choice—"I'll drive myself"—is not always made.
- *Consumers adopt innovation in services more slowly than they adopt innovations in goods.* Once an urban travel mode is chosen, the decision is not often reassessed, given the continuation of benefits from the mode selected. Urban travel policy makers and TDM marketing strategists should make sure that benefits for desirable modes of travel are apparent, significant, and continuing. Such an orientation will help ensure that the potential for mode shifts is optimized (when resistance to changing services is high) and that current customers are maintained. Marketers might also consider slowly changing behavior from one mode to another. If consumers are resistant to changing services, it is probably also true that changes of a greater degree (e.g., from being the single occupant of a car to being a transit rider) are harder to obtain than ones of a smaller magnitude (e.g., from being the single occupant of a car to being a member of a carpool).

As discussed in the first part of this section on services marketing, the "intangibility" of a service often poses a marketing problem. Another problem in services marketing (and, to a lesser degree, in product marketing) is customer retention. Both intangibility and retention argue for the creation of a "membership" organization when marketing a service (*9*) such as an urban travel option. Membership symbols such as wallet cards, special waiting rooms, automatic billing, phone hot lines, and so forth help to make a transportation service more tangible. Frequent patronage by members could also yield discounts, which along with the other tangibles of membership can help retain current customers.

Finally, the services literature talks about the inherent benefits of service customization versus standardization (*9*). Customization may yield exactly what is needed for a particular customer. Good examples are found in law, medicine, and architecture. In urban transportation, the private car or taxi service yields a high degree of customization. The benefits of individually tailoring a service to a customer are obvious, but the negative aspects are not. High customization often yields a degree of uncertainty about the final outcome of the service (e.g., the results of some legal work, architectural design services, or surgery).

Service marketing literature suggests a tempering of these two customization extremes. Some customization should be brought to the mass transit experience, for example, and some degree of predictability should be brought to the highly customized service. As for the latter, the provider of a customized service could break its offering into two components, one predictable and one less so. For example, a doctor may do a clinical analysis for a fixed fee with known outputs (e.g., a blood pressure test) and then embark on the less predictable (e.g., an operation). Providers of a paratransit service might consider clearly communicating the arrival times at fixed locations on a route while leaving the specific arrival times of customized door-to-door service less specified. On the other end of the continuum, providers of mass transit might try customizing their services by doing such things as individual billings for customers and personalized communications and travel counseling.

This has been a brief overview of several aspects of services marketing and its implications for urban transportation policy and TDM. What follows is the application of another area of marketing theory to urban transportation policy—the cultural aspects of consumption.

Cultural Perspectives on Consumption

At the heart of TDM is the notion that people's travel behavior can be changed. However, many are skeptical about the prospects for achieving substantial changes in travel behavior, especially when consumers show such a strong and steadily growing preference for the automobile (*1*). In fact, the *Nationwide Personal Transportation Study* (*10*), based on national samples of several thousand households, showed that the proportion of households not owning automobiles has dropped steadily, from 20.6 percent in 1969 to 15.3 percent in 1977 and 13.5 percent in 1983. Americans made 3.6 percent of their trips on public transit in 1969, and that share declined to 3.0 in 1977 and only 2.6 percent in 1983 (*11*). If the task is to manage and change travel behavior, a first step is to understand the cause of current behavior. In his book *Culture and Consumption*, McCracken presents several insights from a historic and cultural perspective that might enhance the understanding of contemporary urban travel behavior and yield valuable insight for transportation policy and TDM strategies (*12*).

Consumer goods play a significant role in Western cultures, well beyond their utilitarian and commercial value. Their significance consists largely in their ability to carry and communicate cultural meaning (*12*). According to McCracken, the original location of meaning resides in the "culturally constituted world" and is transferred from this world to consumer goods and finally to the individual consumers that possess these goods.

Through their ability to communicate, goods give a visible record to cultural meaning that would otherwise be intangible. They help consumers construct their lives, giving their lives concreteness and allowing the consumers to convey meaning to others. One of the most important messages communicated by consumer goods is that of status. In the past, according to McCracken, the status of individuals was communicated by the age of their possessions. As McCracken would say, patina is this visual proof of age, and it consists of the dents, chips, and surface wear of objects. Historically, patina was a means for families to legitimize their claims of long-standing status. Patina served as their visual proof of status (*12*).

Today, a quite different phenomenon is at work. Consumer goods still serve as communicators of status, but instead of legitimizing the long-standing status of a family, they are able to legitimize the immediate status of an individual. Goods do not have to be in a family's possession for several generations to verify status, but through immediate purchase and use they can help individuals claim status. For example, the ownership of a BMW automobile, a Rolex watch, and Burberry apparel shows that one belongs to a given social niche.

Current travel can be examined as to how it communicates status and thus help explain this behavior. Automobiles are one of the prime means through which individuals in Western societies communicate status. Clothing, housing, and automobiles are all acquired as a "second skin" in which others may see us (*13*). Cars are visual proof of the styles of life that people lead. They symbolize all that is the American spirit. They epitomize the sense of freedom and independence. As it is so well said in a popular television commercial, "It's not just a car: it's your freedom!" If automobiles allow individuals to communicate their levels of status and sense of freedom and independence, what does the use of public transportation communicate? Currently, transit users are seen as lower-class, inner-city workers who lack the resources to own and operate automobiles. Buses, subways, carpools, vanpools, and other high-occupancy modes of transportation are seen as inconvenient to our free and easy lives. They do not tell others of the successes in one's life, but instead signal financial problems, handicaps, and other restrictions.

None of these ideas bodes well for promoting changes in current urban travel behavior. If so much status and identity is wrapped up in automobiles and current styles of travel, how can it be expected that people will change their behavior to a different mode? One aspect of the meaning of goods that has not yet been discussed is their changeable and indeterministic nature. Cultural meanings are not fixed and static but are constantly changing. According to McCracken, cultural categories have an elective quality that makes them subject to rethinking and rearrangement by the individual and other parties. If this is true, marketers can help to rethink and redefine the cultural meanings that are associated with public transportation, for example. Instead of promoting public transportation as a means of saving money, why not promote it as a means of conserving scarce resources and preserving the environment? Public transportation can then be used as a means of communicating a different status, that of a concerned and socially responsible individual.

Currently, public transportation does not reinforce status in any form. One way to begin this reinforcement is through the use of advertising. "Advertising and the fashion system move meaning from the culturally constituted world to consumer goods" (*12*). In essence, advertising brings together the consumer and an aspect of the culturally constituted world within the context of a particular advertisement. It is hoped that the reader of the advertisement sees a similarity between the two and attributes properties in the culturally constituted world to the consumer good. When the known properties of the cultural world come to be resident in the unknown properties of a consumer good, the transfer of meaning is said to be accomplished (*14*).

Although public transportation is more of a service than a good, the same idea of meaning transfer can be applied. In this case, the meaning that needs to be communicated is that the use of public transportation can provide individuals with status as do other modes of transportation, such as the automobile. This could be done by associating successful people using public transportation, in different forms of advertising. It is hoped that the viewers of such advertisements would then begin to attribute the use of public transportation to more successful and higher-status individuals.

Another perspective from McCracken that yields an explanation of current travel behavior is his history of displaced meaning. Displaced meaning consists of the cultural meaning that has been removed deliberately from the daily life of an individual and relocated in a distant cultural domain. Displaced meaning is a way for people to deal with the gap between their real and ideal worlds. Because they are not always able to live ideal lives, individuals remove these ideals from daily life and transport them to a place of safety. Consumer goods are bridges to these hopes and ideals, and consumption is one way of maintaining access to them. People are constantly striving, through consumption, to attain a portion of their ideal worlds. However, when people are able to capture their ideal worlds, or a portion of them, by purchasing these symbolic objects, they immediately remove the meaning from this good and place it in another "out of reach" object. The obtained object is devalued of its meaning in favor of an unobtainable object, and thus the meaning remains displaced. "What has been long sought is swiftly devalued and the individual moves on to another bridge, so that displaced meaning can remain displaced" (*12*).

What implications does the theory of displaced meaning have for urban transportation policy? It is most likely that current public urban transportation is a part not of the ideal world that many are striving toward, but of the real world that they are attempting to move away from. Furthermore, in its present configuration, there is no link between any aspect of public transportation and the ideal world. The purchase of a Porsche or a Jaguar might more closely represent the ideal world in regard to transportation. Much work needs to be done to connect elements of alternatives to the private automobile to the consumer's ideal world.

A final perspective in regard to the cultural aspects of consumption is labeled the Diderot effect by McCracken. Possessions often appear to go together, and through this match, they form a consistency in the life of the user. This harmony or consistency of goods is called Diderot unity. Through this idea of Diderot unities, consumption can be seen as an interrelated phenomenon. Consumers buy groups of goods to be consistent with their own image of themselves and the image they want to convey to others. For example, someone would not want to own a Porsche and live in a trailer park; it would be inconsistent.

The Diderot effect occurs when a new good enters one's life. This new good has the power to transform a current set of goods to a totally new one. Old possessions that are inconsistent with the new "magical" object are discarded; then a whole constellation of goods that are consistent with the new object may be purchased. Although McCracken does not talk about the Diderot effect in the context of service purchases, the principle is probably still at work. An example is the matching of certain entertainment activities (e.g., the opera) with a transportation mode (e.g., a limousine) and an eating establishment (e.g., a French restaurant). Urban transportation policy makers and TDM strategists must consider the contextual implications of the Diderot effect.

Reinforcement Theory

In the early 1980s several articles proposed the merits of a reinforcement theory perspective to the study of consumer behavior (*15,16*). This theoretical perspective is widely researched within the field of psychology, and many applications have been made to educational, clinical, and correctional settings. Outside the original articles, little further theoretical thinking or application has been carried out within marketing in regard to reinforcement theory. However, this perspective has been developed more fully in a transportation context by Everett and Watson (*17*) and in a transportation-marketing context by Everett (*18*). Reinforcement theory is particularly appropriate for TDM because it directly deals with modifying behavior—and this is certainly the explicit goal of TDM.

The basic principles of reinforcement theory are reinforcement, punishment, contingencies, the schedule of reinforcement and punishment, and reinforcement and punishment delay. These will be discussed briefly, with comments on their relevance to urban transportation policy and TDM implications.

First, the concepts of reinforcement, punishment, and contingencies: both reinforcers and punishers follow a behavior and are contingent on it (i.e., the behavior must happen for the reinforcer or punisher to follow). Reinforcers are events that strengthen or increase the odds of future occurrence of a behavior, whereas punishers weaken behavior. As Everett and Watson have pointed out, the current urban transportation system (whether by intent or not) consists of many reinforcers for private automobile use and few punishers (*17*). On the other hand, alternatives to the private car (e.g., mass transit use, bicycle riding, walking, and living closer to work) yield few reinforcers and many punishers. For example, reinforcers ranging from safety to speed, stereo music, air conditioning, deferred payment systems, and prestige and status are contingent on private automobile use. Punishers contingent on transit use are many, from long travel times to filth and crime, waiting in the rain for a late vehicle, the requirement to "hunt for" exact fare, and the social degradation of being a "bus rider."

Reinforcement theory suggests a realignment of these reinforcers if it is desired to modify demand for different travel modes within the urban transportation system. Sleek, clean, dependable transit, possibly on a deferred payment system (credit cards) would be an approach in the correct direction. Punishers for car use in major urban areas could include road user fees and tolls and significantly higher parking fees (possibly even the abandoning of employer-sponsored free parking). Everett and Watson have shown the impact of pricing-based reinforcers on ridership (*17*). Gains of 6 to 58 percent have been realized.

Basic research and application in psychology have shown that it is not only the nature of the reinforcers or punishers that modify behavior, but also the odds of reinforcement or punishment delivery following a contingent behavior.

Deslauriers and Everett found that pricing incentives for transit use increased bus ridership to a greater degree when only one-third of the riders (on an unpredictable basis) received incentives as opposed to every rider (*19*). When developing marketing programs aimed at modifying transportation demand, policy makers might want to consider the differential impact of various schedules of reinforcement.

The time delay between a behavior and the delivery of a reinforcer or punisher is also a critical variable in strengthening or weakening behavior. Although researched little beyond the experimental psychology laboratory, the meaning of this concept to urban transportation demand management policy is striking. The concept is simple: those reinforcers or punishers that come more immediately after a contingent behavior have more power in changing that behavior than do those that follow later.

A quick application of the reinforcement and punishment delay concept to the urban travel scene shows that through an elaborate credit system for the purchase of cars and fuel, punishers that might be expected to reduce this travel mode are distant in time. Reinforcers for mass transit use, such as an improved environment, are also quite delayed. The more immediate consequences for mass transit use are usually punitive, whereas most of those for private automobile use are reinforcing. Although no known application of this concept has been made in marketing or urban transportation, policy could be potentially well served if it were considered. A reduction in easy credit for automobile choices might be appropriate or an immediate and overt recognition (e.g., through media exposure) of the advancement toward improved environmental quality contingent on a company's initiation of a vanpool program. Many logical implementation programs could follow from the concept of reinforcement and punishment delay.

Although this is a quick review of reinforcement theory contributions to urban transportation, the potential for this perspective in developing policy and marketing strategies to manage demand is significant.

URBAN TRANSPORTATION POLICY RESULTING FROM INTEGRATING THREE MARKETING THEORIES

Three theoretical positions in marketing have been put forth. Under each of these areas, many comments have been made as to marketing perspectives that might contribute effectively to urban transportation policy and demand management strategies. These comments were brief, and many more could have been made as each of the theoretical areas is significant in size. However, some of the most interesting policy implications evolve from the marriage of the three theoretical perspectives. One policy implication of this marriage will be introduced here. Clearly, as was the case for each of the theoretical perspectives, much more could be said about their integration.

One of the main points running through the literature on the history of Western consumption is that the material culture is a direct avenue to status. In the terminology of reinforcement theory, consumption behavior of certain material goods is reinforced. One would assume that the further one gets from products and the less tangible a purchase becomes, the harder it might be to link status reinforcement to consumption. In other words, can consumers of a service (such as public transportation) be reinforced with status?

Status seems to be, according to the history of consumption, a major force driving consumer behavior. Present-day public transportation systems provide tangible evidence of neither consumption nor status. Clearly, the ownership of a stylish automobile addresses the problem of tangibility and reinforces status.

Urban transportation policy makers have given little thought to these important variables. Anecdotally, the history of urban transportation adoption verifies the status-reinforcing properties of transportation consumption. The wealthy were the first to have horses, then carriages, then cars. Can it be expected that current public transportation systems, which were made public so that the transportation deprived could be served, would be desirable for those seeking status reinforcement?

The status reinforcement of the material culture is a simple yet profound result of the marriage of the three theoretical perspectives outlined in this paper. The challenge to policy makers in urban transportation is to develop an atmosphere and environment that will foster marketing strategies that reinforce consumers of environmentally relevant travel services with status.

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PART 2

Operations and Technology

Transit-Generated Crime: Perception Versus Reality—A Sociogeographic Study of Neighborhoods Adjacent to Section B of Baltimore Metro

STEPHEN L. PLANO

A research gap exists in the study of crime specific to neighborhoods adjacent to transit stations. A body of data is available listing crime in those neighborhoods, but it is usually available in a form that impedes analysis of relationships between the neighborhood and the transit station—that is, the crime occurrences are tallied without concern as to how the offender traveled to his or her destination or without delineation of where exactly the crime occurred. It is hoped that transportation planners eventually will have data that can address the concerns of residents about potential increases in crime "due" to transit in areas designated for transit stations.

The purpose of this paper is to address a research gap for information related to crime in neighborhoods near transit stations. Although information on crime on transit systems, including stations, vehicles, and parking lots, can be found, virtually no data are available that would help explain a relationship between crime levels and neighborhoods near transit stations.

A crime can be said to occur when an offender breaks a law in force at a certain time in a particular place. Some crime is directed at a physical target, and some is directed at a person. The crime can be defined without the target element but is further described by the type of target (*1*).

The *Uniform Crime Reports*, or UCR, are used widely by criminologists and geographers as a standard form of crime measurement for crimes occurring in the United States. The UCR is compiled by the Federal Bureau of Investigation (FBI) and is divided into 29 types of offenses. The first tier of categories (known as Part 1 or index) are listed as serious and include criminal homicide, forcible rape, robbery, aggravated assault, burglary, theft, and automobile theft. These categories are those typically reported in the media and form the basis for much of the available crime research (*2*).

Although the UCR classification is used often for crime studies, it is just as often criticized for its inherent flaws and biases related to measurement methodology, such as inconsistent reporting by field officers (different officers prepare reports differently, or not at all), lack of reporting by victims who fear retribution or embarrassment, variances in the ways in which local police departments describe and report crime to the FBI, and the lack of data for crimes that are never detected and are therefore uncounted by police statisticians. Another major limitation of the UCR data for planners is that although the place of the crime is documented, the residence of the offender is not recorded.

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Despite such flaws, the UCR is the most efficient, accurate, cost-effective, and practical set of data available to anyone who is studying crime occurrences as discrete events in time and space.

STUDY OF CRIME

A study of crime that involves the exploration of possible transit influences requires research into the concept of "journey to crime": the trip that a criminal takes to gain access to potential targets of personal or property crimes. This commute to crime may originate at the offender's home with a direct criminally oriented destination, or it may involve a multipurpose trip that ties the offender to his or her home and the crime target.

Some of the available research has noted a distance decay concerning the actual travel patterns of criminals (*1*): as the distance between the criminal's origin and target increases, it becomes less likely for that criminal to commit a crime in the target area.

Distance decay for a criminal's journey to crime can be said to follow patterns similar to noncriminal journeys. Most people tend to shop, socialize, and otherwise move about in clusters of trips that are centered about their own homes. It appears that the criminal is no different in his or her concept of commuting to "work." The logic of the distance decay is inescapable when the variables of time, money, and effort are considered as potential friction factors to the journey.

In conjunction with these findings, other research has proposed that residential areas offer little attraction to an offender from outside. Nonresident offenders who have not developed mental maps of an area are less likely to commit crimes in the unknown area. Conversely, more public areas such as shopping centers are more familiar and therefore more attractive to the offender (*3*). It was also found that residential areas rank lowest, transitional and commercial areas highest, and industrial areas in between in terms of target attractiveness.

Because an offender tends to commit crime close to home, it is logical to theorize that similar friction factors will cause the offender to search out targets that possess high potential return with minimal potential risk of failure or capture.

Friction factors can take the form of natural and man-made physical barriers such as streams, roadways, steep terrain, lighting, security locks, gates, fences, and general character of an area. Other, less tangible factors that may influence the offender's perceptions include activity levels, amount of police surveillance, and information passed along by other offenders.

DESCRIPTION OF STUDY

The study area chosen for this paper included the neighborhoods adjacent to the Baltimore Metro subway stations in suburban Baltimore County, Maryland (Figure 1). Adjacent is defined here to mean an area within a 10-min walk of the entrance to the Metro station. These walking limits are cognizant of physical impediments and therefore do not resemble concentric rings about a point of origin.

The Crime Reporting Area (CRA) used by the Baltimore County Police Department to organize data geographically was chosen to represent crime data at the neighborhood level. The CRAs for Baltimore County are neighborhood-sized areas (smaller than census tracts) defined generally by natural and man-made geographic edges such as stream valleys and roadways.

The Milford Mill and Old Court Road Metro stations, opened in July 1987, are located in areas of mixed land use northwest of the Baltimore city line. Areas next to the stations are dominated by small single-family homes situated on lots of

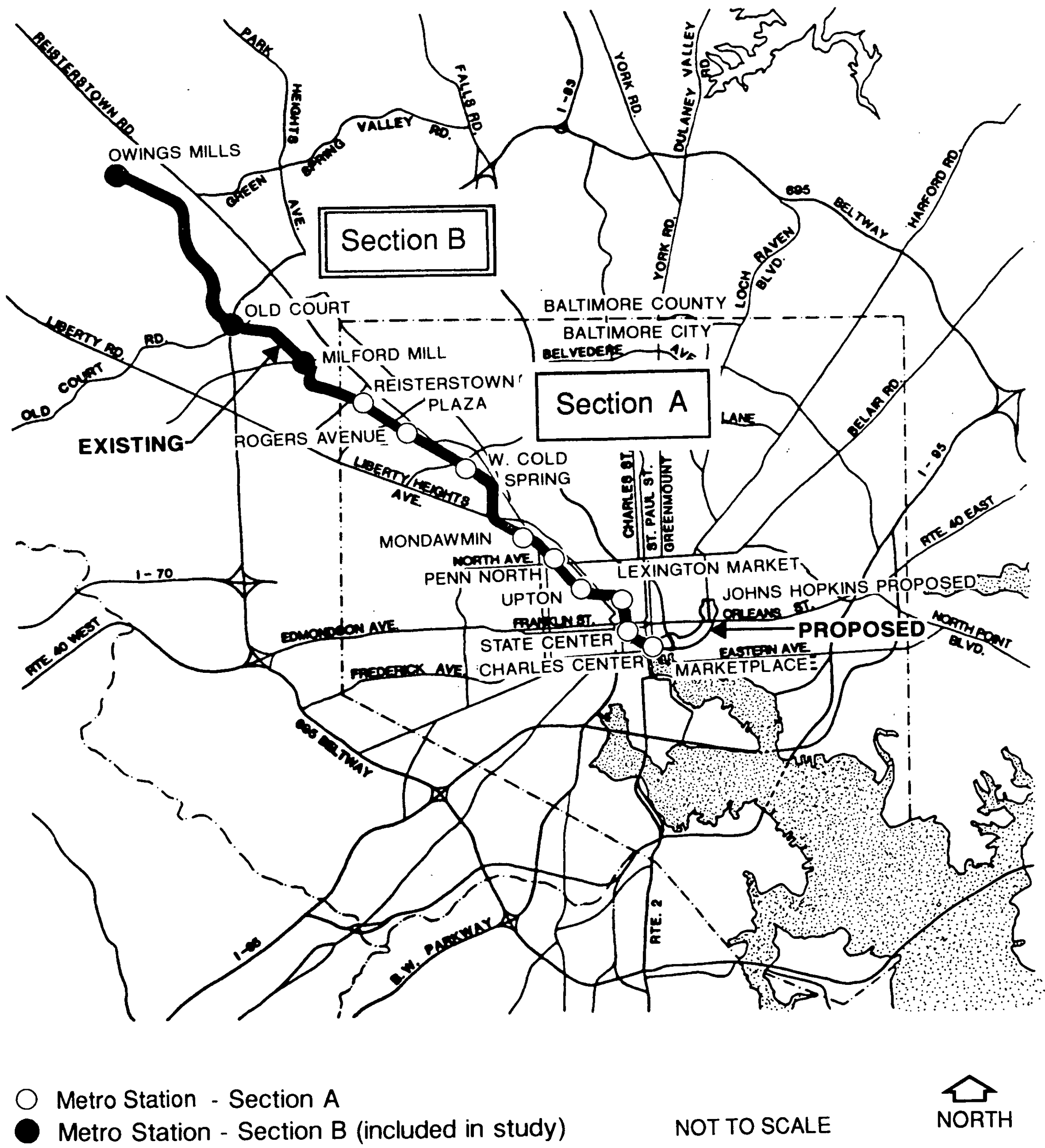

FIGURE 1 Map of Metro stations in suburban Baltimore County, Md.

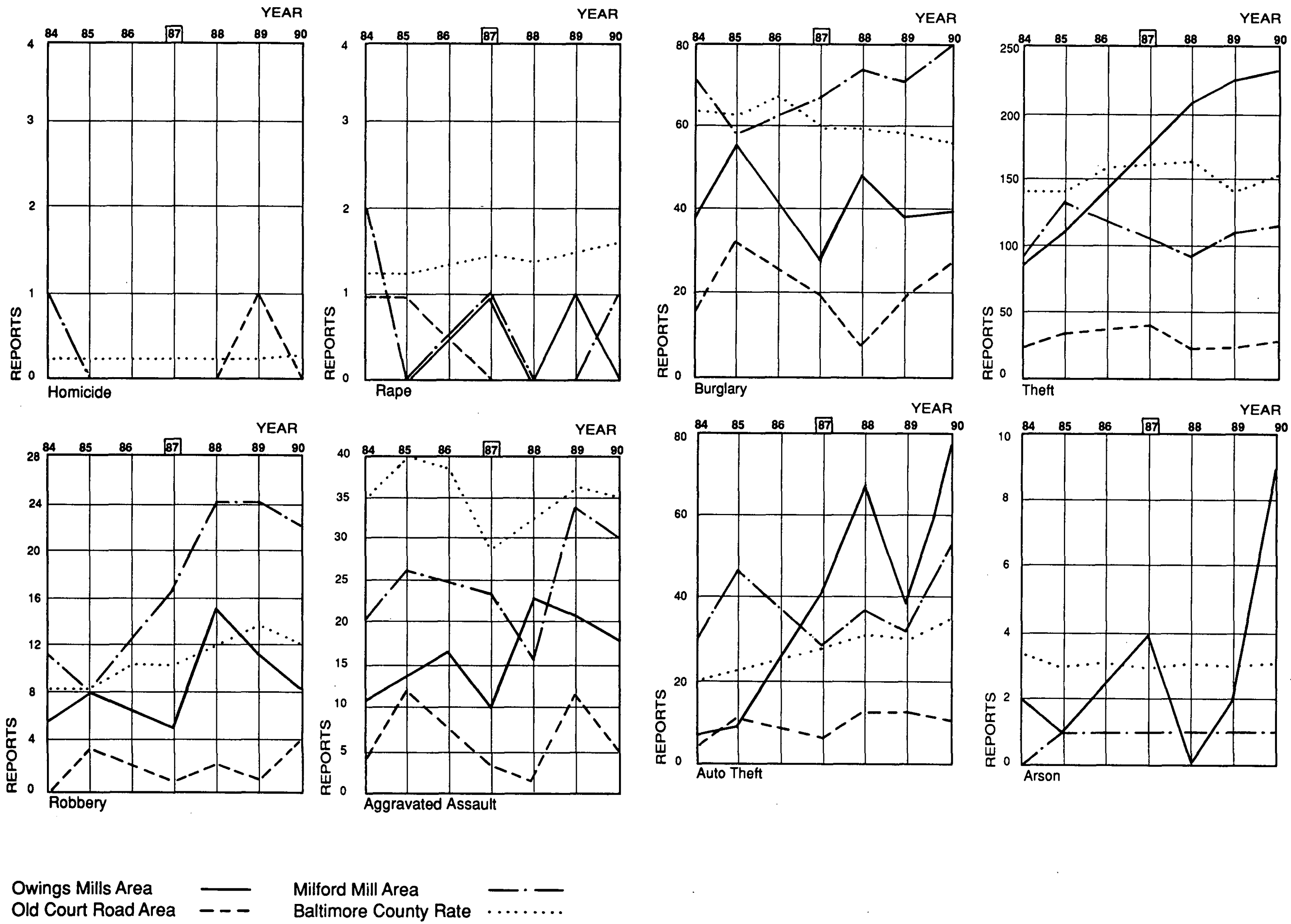

FIGURE 2 Neighborhood crime for Metro Section B, 1984–1990.

about 0.25 acre with some commercial and industrial uses and expanses of apartment buildings. Both stations have large surface parking facilities next to the station buildings.

The land use near the Owings Mills Station (also opened in July 1987) is dominated by the Owings Mills Mall, a large regional shopping mall northwest of the Metro station in the area shown on the figure as the Owings Mills Town Center. The Metro station is situated in the median of I-795, the Northwest Expressway. Surface parking areas for the station are located on both the east and west sides of the highway and are connected by an under-the-highway promenade.

Crime occurrence statistics were gathered for each of the three station areas for eight Part 1 crimes tracked by Baltimore County. The most disappointing aspect of the statistics was that crime locations could not be obtained for transfer to a pin-dot map, which would have illustrated any distance trends or clustering. Data were available only at the CRA level, with no specific locations or addresses.

ANALYSIS

As seen in Figure 2, crime varies significantly by category in the three Metro neighborhoods. A review of the crime statistics gathered for 3 years before Metro's opening of Section B and 3 years after indicates that reported crime is on an upward, though erratic, trend in Baltimore County near these transit stations for most of the major categories. But it is also true that similar upward trends are true for the county in general, as indicated by the county trend line (representing crime occurrences per 5,000 residents as distilled from a rate per 100,000 residents for pictorial purposes).

Whether increases in crime in the neighborhoods of this study can be attributed directly to the addition of a transit station cannot be determined with the data available. The absolute numbers of occurrences are relatively low, and trends are difficult to determine. In addition, the nature of the variables that can influence the reporting of crime discussed previously could have been responsible for some or all of the increases and decreases for certain reporting years.

RECOMMENDATIONS

The geographic unit used by Baltimore County, the CRA, is smaller than a census tract but still so large that it provides only general neighborhood-level data. In addition, demographic data are not available at the CRA level that would allow for direct per-capita comparisons between these study neighborhoods and neighborhoods without Metro stations. Analysis of a demographically similar, radial-oriented suburban corridor of neighborhoods without Metro would provide a control group for more direct and viable suburb-to-suburb comparisons instead of the simplified suburb-to-county comparison presented herein.

Specific locations of crime occurrences would add another level of detail to this study. The dispersion of crime about a transit station could then be analyzed to determine any potential spatial influences or trends. Follow-up studies tracking a perpetrator's place of residence and the manner in which the perpetrator traveled to the crime scene would also be extremely beneficial in the more accurate determination of whether criminal commuters use transit stations. Such studies can be accomplished only if local enforcement officials are willing and legally able to gather these data. Even then, the information may be questionable because of its source—the perpetrator.

Crime as a potential secondary effect of a proposed transit system is an issue that continues to be raised by community groups, especially in suburban areas. In this study some increases in crime have been found, but further conclusions based on the data are problematic.

This paper has scratched the surface of a topic that is in need of further research. It is a topic that is important for the people living near transit stations and the transit professionals planning for future stations and lines. The goal of this paper was to begin to fill a gap in research concerning crime in neighborhoods near transit stations. Further studies should look into working with enforcement agencies to develop data that provide more exact crime locations and include the location of the offender's domicile and the manner in which the offender traveled to the crime site. Establishment of studies of residents' perceptions about crime before and after transit projects are completed would also help planners. This paper has initiated what is hoped will be a significant field of study by planners.

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Guidelines for Development of Passenger, Vehicle, and Facility System Security Program Plans

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FTA's Safety and Security Program goal is to achieve the highest practical level of safety and security in all modes of transit. In order to protect passengers, employees, revenues, and property, all transit systems are encouraged to develop, implement, and maintain a system security plan and program. Increased security should be accomplished through the use of a systems approach with both proactive and law enforcement activities clearly outlined in the plan. The plan should be a complete guide for establishing and maintaining a comprehensive security program for the transit authority and the entire system for which it is responsible: including people, property, procedures, and the environment. A document designed to help transit systems outline and author the sections of a plan to implement an effective security program is summarized. Also summarized is each aspect of a security plan to ensure that when complete, the plan will (a) demonstrate management's commitment to and policy on security; (b) introduce the concept of a system security program; (c) describe the transit system; (d) establish the management of the plan; (e) detail the security program by assigning responsibilities, (e) explain how threats and vulnerabilities will be identified, assessed, and resolved; (f) describe how the plan itself will be implemented to establish or revise the program; and (g) describe how the plan will be evaluated and modified.

To achieve the highest practical level of safety and security in all modes of transit, FTA encourages all transit systems to develop and implement a transit system security plan and program that covers passengers, vehicles, and facilities. To assist transit properties in developing their security plans and programs, FTA contracted with the KETRON Division of the Bionetics Corporation to prepare a guidelines document. This paper summarizes the larger guidelines document and covers each section of an effective plan.

It is important to read the guidelines thoroughly before starting. Lead security personnel may also consult with other transit security professionals; such interaction among transit and security professionals greatly benefits the industry. Next, collect all of the appropriate security-related information within the authority. Third, write each of the specific sections outlined in Figure 1. The outline is designed for both large-scale transit properties and small rural paratransit organizations and may be adjusted slightly as appropriate to each transit system.

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OPENING PAGES TO SYSTEM SECURITY PLAN

The opening pages to the security plan should include acknowledgments, a foreword, and a management policy statement. A wise author will credit all who contributed to the security plan or program. This acknowledgments section should also show an established and working relationship with key local entities. The foreword, which follows, should provide a clear understanding of how the plan is expected to serve as the dynamic structure for implementing an effective system security program, with a succinct expression of the reason that the plan was created.

Without a management commitment and directive or policy statement, the program and plan are almost certain to falter. The system's leader must establish a full commitment to security in the opening pages of the plan. The statement also directs responsibility for security to an individual or group and indicates full support for them and should indicate that the plan is the basis from which security roles and procedures will be implemented on a daily basis.

INTRODUCTION TO SYSTEM SECURITY

The first section of the plan, the introduction, should introduce the concept of system security and present the following key concepts according to the outline shown in Figure 1.

Purpose

A system security plan is of limited value unless it fully defines and implements a system security program. Otherwise, the plan document could simply end up on a shelf, unread and collecting dust.

Current thinking emphasizes identifying potential threats and areas of vulnerability and developing proactive, prevention-oriented approaches that will minimize them. There will, nonetheless, be security breaches; they require reactive law enforcement actions to be defined. This threat and vulnerability management, as applied to all aspects of the people,

ACKNOWLEDGMENTS

FOREWORD

MANAGEMENT COMMITMENT AND DIRECTIVE/POLICY

I INTRODUCTION TO SYSTEM SECURITY
- A. Purpose for System Security Plan and Program
- B. Goal, Objectives, and Tasks
- C. Scope of Program
- D. Security and Law Enforcement
- E. Management Authority and Legal Aspects
- F. Government Involvement
- G. Definitions Within Plan

II TRANSIT SYSTEM DESCRIPTION
- A. Background and History of Transit Agency
- B. Organizational Structure
- C. Human Resources
- D. Passengers
- E. Transit Services/Operations
- F. Operating Environment
- G. Facilities and Equipment
- H. Passenger, Vehicle, and System Safety Plan and Program
- I. Current Security Conditions
- J. Existing Security Capabilities and Practices

III MANAGEMENT OF SYSTEM SECURITY PLAN
- A. Responsibility for Mission Statement and System Security Policy
- B. Management of Program
- C. Division of Security Responsibilities
- D. Proactive Security Committee
- E. Security Breach Review Committee

IV SYSTEM SECURITY PROGRAM: ROLES AND RESPONSIBILITIES
- A. Planning
- B. Proactive Measures
- C. Training
- D. Day-to-Day Activities

V THREATS AND VULNERABILITY IDENTIFICATION, ASSESSMENT, AND RESOLUTION
- A. Threat and Vulnerability Identification
  1. Security Testing and Inspections
  2. Data Collection
  3. Reports
  4. Security Information Flow
- B. Threat and Vulnerability Assessment
  1. Responsibility
  2. Data Analysis
  3. Frequency and Severity
- C. Threat and Vulnerability Resolution
  1. Emergency Response
  2. Breach Investigation
  3. Research and Improvements
  4. Eliminate, Mitigate, or Accept

VI IMPLEMENTATION AND EVALUATION OF SYSTEM SECURITY PROGRAM PLAN
- A. Implementation Goals and Objectives
- B. Implementation Schedule
- C. Evaluation
  1. Internal Review
  2. External Audits

VII MODIFICATION OF SYSTEM SECURITY PLAN
- A. Initiation
- B. Review Process
- C. Implementation of Modifications

APPENDIX A BIBLIOGRAPHY

APPENDIX B GLOSSARY OF SECURITY TERMS

APPENDIX C SECURITY-RELATED BOARDS, PANELS, COMMITTEES, TASK FORCES, AND ORGANIZATIONS

APPENDIX D SECURITY FORMS AND LOGS

ADDITIONAL APPENDIXES.

FIGURE 1 Outline of transit system security program plan.

property, procedures, and environment of the authority, is known as system security. The plan should define and implement a system security program.

Goal, Objectives, and Tasks

Readers of the plan will want to know what it is expected to do. The primary goal, of course, is to implement a program consistent with the policy providing for system security. In this section, broad yet authority-specific objectives supporting that goal should be identified. In addition, each of the objectives should have associated with it a set of specific tasks that are well thought out, reasonable, and attainable.

A sample objective may be to develop an information system that logs all security breaches to support analysis and effective decisions. A sample task associated with this objective could be ensuring that the record-keeping system is able to log incidences by date, location, type, and disposition.

Scope of Program

The scope subsection of the plan should summarize the intent of the program, who is involved (and their functions), what organizations are affected, and what aspects of the system (presumably all) are affected. The scope should clearly relate to the objectives established previously.

Security and Law Enforcement

Transit authorities should take a proactive approach to security. Security breaches, however, will still need to be handled. The authority may rely on its own security forces, private companies, or sheriff's departments to react to security breaches. The plan should discuss here the relative roles of the law enforcement and transit security, including how they work together, communicate, and share jurisdictions.

Management Authority and Legal Aspects

The basis for the creation of the transit authority should be defined. The authority's mission statement and information related to the extent of its specific transit-related responsibilities should also be presented. If the authority is chartered to maintain its own security force, or if the municipal police department is used, the legal basis for such requirements and responsibilities should be defined.

Government Involvement

Most systems depend heavily on supplemental federal, state, and local funds. Include in the government subsection information on the specific sources of all major funding and explain security impacts due to the terms and conditions of the grants. For example, federal rules on third-party contracting regarding record keeping might affect the number of security companies willing to offer security capabilities.

Definitions Within Plan

Various transit and security terms should be defined so that the document will be clear and consistent to all readers. The authority may choose to write general descriptions of the various security concepts in the definitions subsection and to include more detailed formal definitions in an appendix.

TRANSIT SYSTEM DESCRIPTION

The plan will be of interest to many people, not only those familiar with the system. Although the document should be designed as a working tool for transit personnel, it may also be used as a reference by board members, city planners, nontransit police, citizens' interest groups, and government officials. Readers should need to look no farther than the plan itself to understand the nature of security within the system. This section of the plan will describe the transit system for which the plan has been created. Consequently, it will succinctly summarize the passenger, vehicle, and facility components; the operating environment; the role of the safety plan; and existing security conditions, following the outline shown in Figure 1. Most of this material need not be developed from scratch. If it is necessary to generate completely new material, the description or parts of the description may be used for other documents.

In developing this section of the plan, remember that the plan is being developed with a systems approach. A system is a composite of people, property, environment, and procedures that are integrated to perform a specific operational function in a specific environment. The elements of a system are diverse and interactive. Thus the system description must be comprehensive. Consider this big picture and the myriad potential audiences as the description of the transit system is developed.

The transit system description should include subsections addressing the following:

- Background and history of transit agency: give the reader a clear picture of the evolution of the transit system and its place in the community.
- Organizational structure: define the various functional portions of the transit agency administration.
- Human resources: summarize the number of employees, their skills, and the way in which they are divided among the various functional entities within the agency.
- Passengers: describe the passengers that the authority serves, including demographic, population, and ridership information.
- Transit services and operations: introduce the various modes of travel services provided by the agency with summary information about the amount of exposure that they face in terms of hours.
- Operating environment: round out the reader's understanding of the system with narrative information about traffic, weather, geography, crime rates, and any other characteristics that describe the local environment.
- Facilities and equipment: provide appropriate information on the various facilities and equipment owned and operated by the authority.

Passenger, Vehicle, and System Safety Plan and Program

Over several years, FTA, through its research arm, the Volpe National Transportation Systems Center, has recommended that each authority develop a passenger, vehicle, and facility system safety plan and program. There are fundamental differences between safety and security. Safety is freedom from accidental danger, whereas security is freedom from intentional danger. The structure of the plan should be very similar to the safety plan, except that the concerns are not with accidental situations, but with deliberate actions taken by perpetrators to steal or damage property, harm people, or disrupt operations. This subsection of the plan should summarize the overall philosophy of the safety plan and program and integrate it with the security plan and program.

Current Security Conditions

The transit system description should also develop a portrait of current security conditions. Summarize the kind of security breaches that have occurred and are being addressed by this plan. Include documentation on the frequency of problems experienced during the previous year and other previous periods. Examples of security breaches may include, but are not necessarily limited to,

- Assault and battery
- Bomb scares
- Computer data base intrusion
- Disorderly conduct
- Drug abuse and sales
- Exhibitionism
- Facility and equipment damage
- Fare evasion and dodging
- Graffiti
- Lewdness
- Mugging
- Rape
- Sabotage, destruction, and altering
- Stock/parts shrinkage
- Terrorism
- Theft
- Trespassing
- Vandalism

The authority may want to develop a comprehensive list of security breaches and demonstrate, in a frequency-of-occurrence table, that it is free of some security problems. By identifying problems experienced by similar transit authorities that could arise locally, the authority prepares itself to address potential security problems.

Existing Security Capabilities and Practices

A subsection should summarize what is being accomplished by the authority to maximize security, including both proactive and responsive measures. In this subsection summarize the major proactive methods, procedures, devices, and systems that currently exist to prevent or minimize security breaches. They may include committee work, analysis, training programs, passenger coaching, and proactive security equipment.

For example, the authority may have created a proactive security review committee responsible for identifying potential and existing problem areas, developing standard operating procedures, and installing security devices. If the proactive security committee has been asked in previous periods to address certain issues, those measures should be included here. If the authority has developed data bases on security breaches, then the analysis of the collected data, the conclusions drawn, and the activities that have been implemented to improve security should be discussed. Information on any security-related training that has been completed by authority personnel should be noted. Training might, for example, include such courses as those offered by the Transportation Safety Institute in Oklahoma City related to terrorist threats such as bomb scares. Any passenger coaching that the authority has accomplished should be reported, such as exhorting passengers through advertising to closely guard their belongings at all times. Use of intrusion alarms, motion detectors, and other devices on facility entrances should be discussed.

The authority should also try to include the law enforcement community in proactive, preventive activities, and a description of those activities and the benefits realized should be discussed here as well.

No matter how proactive the authority, there will still be some security breaches. The capabilities of the authority and other law enforcement agencies to respond to a security breach on the transit system should be discussed.

MANAGEMENT OF SYSTEM SECURITY PLAN

Another section of the plan should account for each of the following security management functions:

- Developing the mission statement and overall system security policy,
- Managing the security program,
- Assigning specific responsibilities to staff, and
- Establishing proactive security and security breach review committees.

This section may therefore follow the outline originally shown in Figure 1.

Responsibility for Mission Statement and System Security Policy

A successful security plan requires leadership from the top of the organization and involvement at all levels. The plan should therefore identify who develops and signs the mission statement—usually an executive director or managing board—and who is responsible for setting security policies.

Management of Program

There are basically two structures for managing a security program. In smaller systems, the transit system manager has many responsibilities, including overseeing the program and carrying it out on a daily basis. In larger systems, the transit manager is ultimately accountable for system security but is more removed from daily operations; thus, it is likely that another individual would coordinate the daily activities of the program. This portion of the plan should state which management structure the system uses for its program and assign the following management activities:

- Ultimate responsibility for secure transit system operations;
- Communication of security as a top priority to all employees;
- Development of relations with outside organizations that contribute to the security program and with investigatory agencies such as the National Transportation Safety Board;
- Appropriate action on all security concerns brought to his or her attention;
- Identification of potential security concerns in any part of the system's operations;
- Active solicitation of the security concerns of other employees;
- Liaison between the proactive security and security breach review committees and transit system employees; and
- Assurance that the plan is carried out on a daily basis.

Division of Security Responsibilities

The plan should list all major positions within the security organization and their respective responsibilities, starting on a new page for each function to allow for easy revisions. For each position, summarize the overall security responsibilities, place those responsibilities in the context of the position's other work activities, and include a list of security-related tasks.

Proactive Security Committee

A proactive security committee should be created. Its major task is to identify and neutralize potential security problems before they happen. The committee should conduct systemwide security assessments, make sure that new procedures and facilities incorporate security in their design, develop and review training programs geared to security, look for new techniques that will improve security, and actively promote improved security awareness. This committee should also be responsible for security reviews that determine compliance with management policies, rules, regulations, standards, codes, and procedures.

The people who serve on the proactive security committee should represent various parts of the transportation organization and the local community. Having five to seven members allows the committee to possess a broad representative base and to retain manageability. Outside members could include representatives from the local police department, local officials, board members, and concerned leaders of community organizations. At monthly meetings members should report on security-related concerns, review potential problems, and designate individual members to investigate security issues. Once a security concern is brought to the attention of the committee, representatives should be chosen to evaluate the potential problem.

Security Breach Review Committee

A security breach review committee should also be established to identify and investigate actual security breaches to understand the deficiencies of the security program. Whereas the proactive committee seeks to prevent security breaches, the breach review committee looks at incidents that have already happened. In smaller transit systems, the two committees may be combined as a single security committee.

The incidents that the breach committee investigates may be controversial or sensitive. Therefore, the committee members must be objective individuals trusted by management and other employees. The committee members should include management, nonmanagement, and persons from outside the transit system.

The committee should review security incidents to determine whether the breach occurred because of incorrect policies or procedures, the failure of staff to carry out procedures, an accepted risk, unforeseen technology or action against the system, or some combination of these reasons. The committee may be able to recommend specific actions to prevent future security breaches of a similar nature or may refer a security breach to the system manager or the proactive security committee and ask them to develop preventive measures. The plan should spell out the extent of the authority of the breach committee in recommending actions or changes in security policy.

SYSTEM SECURITY PROGRAM: ROLES AND RESPONSIBILITIES

Individuals throughout the system will accomplish the overall security goals and objectives only if they are assigned roles and responsibilities in the form of procedures. A section of the plan should outline all of the regular security activities of the system. All of the tasks necessary to accomplish the goals and objectives established earlier in the plan will be assigned to specific individuals and groups, thus creating a comprehensive working document. These components may be organized according to the outline shown in Figure 1.

In many ways, this might be called the procedures section; it should be very specific, including tasks, assignments, standard operating procedures, and emergency operating procedures. The level of detail with regard to actual procedures means that the plan must be kept open and revised. The system must be willing to update the plan as ongoing activities change. It should combine those activities already being conducted and those to be implemented.

Each task must also be assigned to a specific position responsible for its accomplishment. This aspect of the security program cannot be overemphasized. "Roles and responsibilities" is included in the title of this section to emphasize the need for people to take responsible action. Were the plan to consist only of procedures, there would be no guarantee that any tasks would be carried out, nor that any objectives would be accomplished.

Planning

The subsection on planning should outline all security planning activities and assign those functions to individuals. After the development of the first plan, most planning activities either will be ongoing or will grow out of the process of identifying, assessing, and resolving security threats and vulnerabilities. Regular planning activities might include meeting with the local chief of police annually to discuss long-term issues, reviewing the success of the security committees, establishing monthly security planning meetings with managers, and soliciting ideas from all staff for improved security.

The system's board of directors will play a role in the planning of security activities by way of approving the initiative to develop a plan and by reviewing and approving the plan. It should be made clear that the board may also assist in security planning by communicating any particular security concerns to top management. Security might also be placed on the board's agenda at a regular interval.

General planning responsibilities (probably relegated to the general manager or lead security officer) should be stated explicitly here. The lead security officer might also have such planning responsibilities as assisting the general manager in the overall development of the plan, writing specific portions of the plan, coordinating with other departments in the establishment of security procedures, and serving on the proactive security committee.

Other managers and supervisors have a wealth of understanding of the operation of the system and should be consulted by the security staff and committees. Managers should also be responsible for reviewing the draft plan, providing input on the implementation process, soliciting security concerns and suggestions from staff, communicating appropriate issues, and considering security in their normal planning activities.

All other staff can assist in security planning by sharing their security concerns and ideas for improvement through a supervisor, suggestion box, or appropriate security staff.

Proactive Measures

Proactive measures may be developed at the time of writing the plan to address recently discovered security problems, especially in the case of the first plan. Other proactive measures may have been recommended by the proactive security committee, or may have been only recently implemented. Because the system will not always want to wait until the next plan revision to implement proactive measures, some may be in full swing by the time of the update.

Briefly describe the problem each new proactive measure is designed to mitigate and the proactive measure, then assign responsibilities for each. Proactive measures that establish new operating procedures may refer to those procedures as presented later in the section on day-to-day activities. Yet-to-be implemented proactive measures should also include the implementation tasks necessary to initiate the new measures.

Training

Security training should be established for all personnel. At a minimum all employees should be given enough training to carry out the security responsibilities expected of them. Security "training" may be as little as discussing security during all regular training programs or as much as sending staff to national workshops on transit security. This subsection should describe all training conducted in the interest of increased security, whether proactive or responsive, referencing any appropriate training documents; include detailed descriptions of training for security staff. This subsection should also describe all new training required to implement any new proactive training measures.

Day-to-Day Activities

Since the subsection on day-to-day activities will describe transit procedures in detail and the security program and plan are being developed using a systems approach, this subsection should be of significant size. It should consist of standard operating procedures (SOPs) and emergency operating procedures (EOPs). This subsection will be more specific than the earlier ones that described programs and responsibilities.

SOPs are the daily activities and tasks intended to accomplish any function within the transit system. They usually comprise the rules and policies of the transit system. Those that affect or are affected by security need to be described here and include, but are not limited to, such activities as

- Operators' leaving the vehicle for breaks and at the end of shifts;
- Securing of the building, lots, and yards at the close of business;
- Distribution of facility keys and assignment of access;
- Termination of employment;
- Collecting and counting revenue;
- Patrolling of facilities;
- Daily activities of security staff;
- Response to potential security breaches;
- Security-related activities of station attendants, train operators, and drivers; and
- Operator procedures for handling threats.

EOPs are the special procedures for nonroutine but serious occurrences, such as responding to alarms. EOPs also include contingency plans for nonpredictable occurrences that may have critical consequences, such as power failures or natural disasters. This subsection should detail the responses to actual security breaches, as well as all other EOPs that may affect security, including at the very least:

- Emergency reporting
- Emergency handling by security staff
- Emergency actions by front-line staff

- Dispatcher responses
- System actions for
  - Minor security beaches
  - Crimes against passengers
  - Violent crime
  - Burglaries
  - Other specific security breaches
- Incident investigation
- Media communications
- Contingency plans for
  - Power failures
  - Natural disasters
  - Terrorism

The format for a set of operating procedures includes a separate page for each procedure, title, affected personnel, level of restriction, list of procedures, and highlighted changes (optional). They may be organized in any fashion that is clear to all readers.

THREAT AND VULNERABILITY IDENTIFICATION, ASSESSMENT, AND RESOLUTION

A transit system by its very nature is vulnerable in various ways, because it owns property in remote public spaces and collects money. Vulnerability is the susceptibility of the system to a particular type of security hazard. Vulnerabilities are things that the authority can take specific defensive measures to correct, such as putting guards on trains or doing background checks on money handlers. Threats are specific activities that will damage the system, its facilities, or its passengers. For example, threats include the intent to commit personal assault and vandalism. A potential security problem exists when these two components, threat and vulnerability, coincide. It is impossible for a system to be completely secure, just as it is impossible for a system to be perfectly safe: security therefore becomes a process of risk management.

Many authorities discover that a lack of statistical and historical data on incidents frustrates attempts to resolve problems. This section of the plan should establish methods to collect and communicate security information so that threats and potential threats (vulnerabilities) may be identified, examined, and resolved appropriately.

Threat and Vulnerability Identification

The subsection on threat and vulnerability identification describes the methods that the system will use to identify its threats and vulnerabilities. It is necessary to identify separately the major vulnerabilities of the system and the threats to which the system is subject, so that assumptions about vulnerability do not hide the possibility of problems with threats. Once these are brought into focus, security resources can be applied to solve specific problems.

Security Testing and Inspections

The primary purpose of security testing and inspection is to assess the vulnerability of the system to a security threat. It can also enhance preparedness and promote security awareness.

A three-phase approach is recommended to evaluate security preparedness. The first phase should confirm equipment preparedness, ensuring that security equipment is operable and properly located. The second phase should assess the proficiency of employees in how and when to use the equipment provided. The third phase should evaluate complete security systems, with exercises requiring coordination between different areas. This phased approach reveals system deficiencies in a useful way. For example, personnel cannot perform well if equipment is not available in good repair.

Data Collection

Within the system, many sources of information can help a security manager allocate resources, including incident and breach reports, passenger complaints, and personnel records. The plan should identify these sources, prescribe procedures for accessing this information, and state limits on its distribution. It should also identify how sources of outside information such as local police reports and the U.S. Department of Justice *Uniform Crime Reports* are obtained and used.

An incident report that collects information about security incidents should include

- Date and time
- Location
- Transit mode affected
- Persons involved
- Narrative of incident
- Estimated cost of damage
- Service disruption
- Security action taken
- Supervisor

These simple reports should be completed at the lowest level possible. They should not be used in investigations but are to alert the security system to threats so that improvement actions can be taken.

Reports

Reports provide summary data concerning the security information that has been collected. The subsection on reports should describe the types of security report to be developed and their distribution. Periodic management reports provide upper management with summary information on security breaches, costs, and ongoing security projects. Statistical reports should be more detailed and used by security staff to determine where problems are occurring and to identify any trends. An incident and security breach data base with a few key indexed fields can provide sufficient information to satisfy special request reports. The plan should place limits on the distribution of the various reports because they will contain sensitive information.

Security Information Flow

Another subsection should describe how the security information will be stored and move through the transit system.

All security information should be sent to a central point. For small transit systems, this information can be kept in files and used periodically to review security performance and to produce statistical reports. In a large system, a security data base should be developed to store, analyze, and retrieve security information. The plan should describe who will receive what security information, considering the sensitivity of the information, its usefulness to the person receiving it, and alternative ways of making this information available.

Threat and Vulnerability Assessment

The security information collected and communicated must be analyzed to determine where the system is vulnerable and what threats are most likely. The plan here should assign responsibility for security assessment and describe how the information will be analyzed and describe what will be done with results.

Responsibility

Since the results of the assessment will direct the deployment of security assets and determine which areas of the system will be protected, the individuals assigned to conduct the threat and vulnerability assessments are critical. The plan should describe minimum qualifications of the analysts, including security experience, knowledge of the system, familiarity with the community, and knowledge of statistical methods and their limitations. The system may wish to rotate responsibility to keep the direct experience level of the analyses high and current.

Data Analysis

It is necessary to describe how the information will be analyzed. Vulnerability and threat are the two major factors involved in this analysis, which can be performed by first listing all of the facilities and systems that make up the transit property. Next, across the other dimension of a matrix, all possible threats, identified in incident reports or from police sources, are listed. The susceptibility of each facility or system on the list to each threat is assessed. When the matrix is completed it will reveal where security problems are most likely.

Frequency and Severity

Once vulnerability has been assessed, there is a need to predict which threats are most likely to occur. The plan should direct that threat analysis be conducted separately from the vulnerability analysis, otherwise evaluators may focus only on perceived threats and not on the real vulnerabilities. The threat analysis should rank each vulnerability on the basis of the likelihood that the threat will occur and the severity of a potential breach. When a high threat coincides with high severity and high vulnerability, security should be focused on that area.

Threat and Vulnerability Resolution

Some threats may demand emergency response, others may require a long-term project, and still others may just be accepted with no action taken. A subsection will need to discuss the factors that go into making such decisions.

Emergency Response

The plan should identify the criteria that activate certain emergency responses. A policy should be set for the appropriate type of response to each type of threat, depending on specific conditions. The plan should also describe the mechanism for activating emergency response, including who is authorized to initiate an emergency response, what levels of response are possible, and for how long emergency responses can be maintained.

Breach Investigation

Describe how incidents will be investigated. The goal of a breach investigation is to determine what circumstances led to the breach. Breach investigations and resulting reports submitted to management for action should describe

- Breach
- Source of threat
- Location
- Equipment involved and its physical condition
- Human factors
  - Conditions at time of breach
  - Training and knowledge of procedures
  - Performance during breach
  - Injuries
- Environmental conditions
- Actions taken to mitigate breach
- Command and control effectiveness
- Probable cause
- Recommendations

Research and Improvements

The security analysis will sometimes reveal a problem requiring additional study to determine ways to manage the risk. New technology often offers security improvements that a progressive system can adopt to its advantage. The plan should provide criteria for undertaking long-term improvements.

Criteria should also be established for acceptance of a new system. It should be able to prove itself in terms of effectiveness in an area of vulnerability, cost with a rapid payback period, and life-cycle dependability. Demonstration periods should be used to verify all claims for the new system before a full commitment is made.

Furthermore, the plan should provide a means for employees to recommend improvements to the system. This has been shown to be one of the most cost-effective and productive sources of new ideas. Consideration of employees' proposals will also instill greater commitment.

Eliminate, Mitigate, or Accept

The plan should recognize that there are three possible alternatives in resolving security problems. The first is to take steps to eliminate the problem, through redesign, retraining, or change in procedure. Although preferable, this is frequently not possible with available resources. The usual choice is to mitigate the threat. In some cases the risk will just have to be accepted, when the threat is so remote that it is not likely or its impact on the system may not be sufficiently dangerous. The factors that go into these decisions should be specified in the plan.

IMPLEMENTATION AND EVALUATION OF SYSTEM SECURITY PROGRAM PLAN

A section of the plan will provide details on how the program plan itself will be implemented and how progress of implementation will be evaluated. This is crucial to the establishment of an effective security program. Implementation will require development of three subsections as shown in Figure 1.

The first time a plan is developed and implemented, the planning process will take somewhat longer than it will in future years when the framework of the program is already established and proactive security measures are being developed regularly by the proactive security committee. In modifying and implementing a program that is already in place, most of the plan is already written. If the program in place is effective, many of the changes and solutions will have already been worked out.

Implementation Goals and Objectives

Major goals and specific objectives should be established for the implementation of the security plan to ensure that all transit system personnel understand exactly how the security program affects them, that the program receives appropriate support from management, that the activities described in the plan are undertaken, and that the system has the tools necessary to carry out the plan.

The primary goal of implementing the security plan will, of course, be to establish (or modify) a system security program. Other goals will support the primary goal. The authority should adopt implementation goals appropriate to its own system. Some important goals are to describe clearly the system security program and to describe accurately the system, the context of the program, and the security activities.

Supporting objectives may be to ensure that the plan is comprehensive and complete, that all managers and supervisors understand the objectives of the program, and that the plan is current. Another supporting objective might be to evaluate the security plan.

Another goal that defines the implementation of the security plan is that of communicating the program to all affected persons. Supporting objectives would be to obtain concurrence from the board of directors, distribute the security plan to all managers and supervisors, require managers and supervisors to communicate the plan to staff, and resolve all questions related to the plan and program. The plan should be distributed to managers and supervisors first, so that those supervising others will be completely familiar with the security program before full implementation is initiated. If the plan contains all of the detail necessary to prevent and counter security breaches, it should not be shared with the public. For example, SOPs for fare revenue collecting and counting should be established during the security planning process but should not be distributed to every employee. Abridged plans may be distributed to most staff.

Another important goal of implementing the plan is to ensure that all transit personnel have the means to accomplish assigned responsibilities. Understanding the specific changes that affect them most is key to this process. Supervisory staff must clearly explain these changes and provide staff with the necessary skills to perform new tasks.

During plan implementation, both the proactive security and security breach committees should be established. If the committees are already established, the membership and organization may be changed as necessary.

Implementation Schedule

To carry out implementation, a timeline with specific milestones should be developed on the basis of the implementation goals and objectives, proceeding chronologically from the completion of the security plan document to the beginning of the formal yearly plan modification process. The schedule should include specific dates for each implementation task.

Evaluation

Constant evaluation of the program will be necessary during implementation. The evaluation process should extend from the initial draft of the plan document through full implementation. The evaluation must reflect the fact that system security is based on a comprehensive planning process for a program that extends throughout the entire system. Consequently, the plan should benefit from the review and input of internal management staff as well as external audits. This section of the plan should briefly explain how implementation will be evaluated.

Internal Review

During the implementation stages, when roles and responsibilities are assigned and new programs initiated, managers must provide constant feedback to the lead security staff. Although the supervisory staff will be busy communicating new tasks and training as necessary, managers should endeavor to step back and assess the effectiveness of implementation. Lead security staff may meet weekly during implementation to make use of this feedback and to smooth the implementation process. The security committees should evaluate the plan and its implementation as part of their regular agendas to ensure that priorities are appropriately addressed.

External Audits

Regulatory agency, peer group, or consultant reviews should take place after the program has been implemented but before the plan modification process has begun. Doing so will enable the external reviewers to evaluate the program during a normal state and allow lead security staff enough time to evaluate feedback and to prepare an effective modified plan. A subsection should identify the techniques that will be used to evaluate formally the program from outside the system. It should include a schedule for requesting external audits, contacting the executing organization, assisting evaluators, and discussing results.

MODIFICATION OF SYSTEM SECURITY PLAN

The plan is intended to be a living document that is used daily. The day after implementation activities are initiated, the plan will begin to be considered for modifications, but security officers should not devote their time to constant revision of the plan. The plan can be the depository of notes, sample forms, and memos. When the yearly revision of the plan occurs, the security officer should not have to go back and recreate history in order to update the document.

Initiation

The actual process for initiating modifications to the security program plan will be defined here. For example, the plan may state that distributed copies will contain a memo or form requesting that the readers or users provide comments on any part of the plan that they believe is inadequate or inappropriate. The plan may state that the security officer and his or her staff will maintain a tickler file so that all information is available in one location and integrated when revisions to the plan are required. The plan should also identify the procedure to be used when a modification to the program needs to be implemented immediately.

Review Process

The actual process used by the security department and those individuals responsible for modifying the program plan needs to be discussed. For example, the proactive security committee could be tasked with reviewing the plan and comparing it with actual operational experience four times a year to identify necessary changes. Another approach might be to establish a small committee 9 months after approval of the existing plan that would modify it or identify necessary changes. Mechanisms for including changes suggested by other department heads or the general manager should also be delineated.

Implementation of Modifications

Modifications to the plan can be manifested in several ways. For example, new procedures, staff responsibilities, or forms may be considered to be of enough value to require immediate implementation. In such instances, appropriate pages of the plan can be revised, approval of their content sought and obtained, and the revisions disseminated to all recipients of the plan. Modifications that can be implemented without extensive training can be instituted on an ongoing basis under the direction of the lead security officer.

CLOSURE

The system security program plan should be a complete guide to establishing and maintaining a comprehensive security program for the authority and the system for which it is responsible: this includes people, property, procedures, and environment. Increased security should be accomplished through the use of a systems approach with both proactive and law enforcement activities clearly outlined in the security program plan.

When complete, the plan document will have

- Demonstrated management's commitment and policy on security;
- Introduced the concept of a system security program;
- Described the transit system;
- Established the management of the plan;
- Detailed the security program by assigning responsibilities;
- Explained how threats and vulnerabilities will be identified, assessed, and resolved;
- Portrayed how the plan itself will be implemented to establish or revise the program; and
- Described how the security plan will be evaluated and modified.

Additional information in the appendixes will make this a complete security plan and valuable security reference.

APPENDIXES

Appendix A: Bibliography

Including a bibliography of good publications related to transit security contributes to the usefulness of the plan and demonstrates that significant research was considered and that the concepts in the plan are in concert with industry standards.

Appendix B: Glossary of Security Terms

A number of different individuals can be expected to read the plan. A glossary of security terms will give all readers the information necessary to appreciate fully the plan's content.

Appendix C: Security-Related Boards, Panels, Committees, Task Forces, and Organizations

A third appendix should define all security-related organizations to which the authority and its personnel belong. There will also be organizations that are potential resources. The section should list all resources that are person-based.

Appendix D: Security Forms and Logs

When the initial plan is created, the authority may already be using a number of forms and logs in day-to-day operations. Forms should be acquired, catalogued, labeled, and included in this appendix and any logs should be listed. Forms and logs from other authorities may be included here as examples being considered.

Additional Appendixes

Since the plan will be tailored to meet the requirements of the local authority, any other appendixes that may be needed or useful can be included.

ADDITIONAL INFORMATION

More detailed guidelines will be available through William T. Hathaway, Volpe National Transportation Systems Center, Cambridge, Massachusetts.

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Computer-Assisted Optimization of Train Crew Size for On-Board Fare Collection

RONALD J. F. YEE

A personal computer–driven computer model that simulates the fare collection workload aboard passenger trains of the Metro-North Commuter Railroad is described. Three distinct formulas were developed to approximate most of the workloads experienced by the on-board train crews as they collect fares and fulfill train operating responsibilities. The recommendations produced by the output of these simulations provide vital guidance to Metro-North management seeking to provide the optimum level of on-board train staffing with regard to fare collection. In this manner, Metro-North initially reduced crew costs by lowering the number of conductors and assistant conductors required to cover all passenger trains. Since the initial use of these computer simulations in 1984, Metro-North has been able to provide an increased level of train service with more frequent and longer trains and to carry more than 20 percent more customers with a lower number of conductors and assistant conductor positions than required in 1984.

The Metro-North Commuter Railroad currently receives more than $231 million/year in fare revenues from its customers. The methods of payment for passage on the railroad include monthly or weekly passes, 10-trip tickets, one-way tickets, and on-board cash fare sales. All of these methods of payment require the train crew to check each customer to ensure that all customers have a valid ticket for their ride.

All Metro-North trains operate with a minimum crew of an engineer and a conductor. The deployment of assistant conductors depend on factors that include safety, train operation requirements, passenger loads, and fare collection. To minimize operating costs, the railroad strives to maximize the efficiency with which its assistant conductors are assigned to all passenger carrying trains. The railroad must provide a sufficient number of on-board train staff (conductor and assistant conductors) to properly collect fares from all of its customers. The number of staff required for each train is highly dependent on factors that include

- Maximum passenger load,
- Number of cash fares sold aboard,
- Distribution of total ridership during entire trip,
- Number of passengers boarding or disembarking at intermediate stations (also called intermediate or way riders),
- Period of operation (peak or off-peak service and fares),
- Operating schedule and station stopping pattern (local, express, or zone express service),
- Number of fare zones served,
- Length of time between passenger stops,
- Number of cars open for passenger occupancy,
- Station platform length and configuration (high or low level),
- Balancing the assignment of train crew personnel,
- Train operating procedures, and
- Other relevant factors in the expected work load (may or may not be related to fare collection needs).

Planning and Development Department, Metro-North Commuter Railroad, 347 Madison Avenue, 20th Floor, New York, N.Y. 10017.

Metro-North has developed three train staffing formulas to simulate the fare collection workloads most often encountered by train crews. Each of these formulas specializes in a particular type of service pattern (e.g., multiple-stop locals, off-peak-period expresses, and peak-period zone expresses). These simulations provide the railroad with an important indicator as to the number of train crew members that each train requires. Altering the data inputs to these formulas can also enable management to assess the impact of schedule and ridership changes on train staffing. These three formulas and all input data reside on a Lotus 1-2-3 spreadsheet where each column of data represents a specific function or type of data. Arithmetic manipulation of the data in the columns generates outputs specific to each row of data.

Through the application of these train staffing formulas to all passenger-carrying trains, Metro-North has realized a considerable savings from reduced operating costs and improved its on-board fare collection efficiency. During 1984–1985, the initial year that this methodology served as a source of guidance in determining train crew size, the railroad was able to reduce the number of required conductor and assistant conductor positions to cover all passenger-carrying trains from 425 to 381. In the years since, Metro-North has used this formula to optimize continuously train crew size. A combination of physical plant, rail car, and service improvements as well as an aggressive marketing campaign has increased all categories of ridership on the Metro-North commuter rail system. With this increase in the number of total customers carried, an increase in the train staff requirements has been necessary to operate the higher number of trains.

The train staffing formulas have been an important tool in keeping the incremental crew costs associated with the ridership and service increases to a minimum. It should be noted that despite a growth in ridership of more than 20 percent and the operation of a greater number of passenger trains, the total number of conductors and assistant conductors required to cover the scheduled service in 1992 was 415, lower than the number needed in 1984.

It can be envisioned that a proof of payment system may be adopted in the future to make further economies in train crew costs. However, until such a policy decision is made, the continued use of these formulas will enable Metro-North to minimize and control its train crew costs by distributing and assigning them with maximum efficiency.

Metro-North's train staffing agreement with the labor unions representing the train crews is specific to the train and not based on the number of cars assigned to any one train. By agreement, the minimum required staffing for any Metro-North train is an engineer and a conductor. In determining the need for additional staffing, the agreement states that the management of the railroad reserves the right to determine the number of assistant conductors any train shall have assigned. A 60-day notification procedure for train crew size reductions is included in the labor agreement with the United Transportation Union, which represents the conductors and assistant conductors. A grievance and arbitration procedure is provided in the union contract for occasions on which the union has a dispute with the railroad on matters related to train staffing.

ON-BOARD WORKLOAD DETERMINATION

Metro-North performs on-board and station counts on all trains periodically with management personnel. A reliable data base is critical to the accuracy of this analysis.

Collectible Data

Collectible data include the following:

- Ridership counts: number of customers boarding or alighting
  - –At origin/destination [the central business district (CBD), which in this case is Grand Central Terminal (GCT)], and
  - –At intermediate stations along the line.
- Fare collection data: number of cash fares sold and prepaid tickets normally collected by the train crew.

Train Operation Data

Train operation data include the following:

- Number of cars in consist: number of cars open for passenger occupancy.
- Type of railcars (special characteristics): the oldest cars in the Metro-North fleet have manually operated doors. Additional train crew members are required for customer safety.
- Number of stops and total running time
  - –Train crew is required to suspend fare collection tasks to perform station stop duties: door controls, safety checks, and so on;
  - –Total time available to perform fare collection tasks; and
  - –Longest nonstop run between stations providing an uninterrupted period when the train crew can perform a fare collection sweep.
- Type of station platforms
  - –High-level platforms and automatic train doors increase the level of customer safety. These trains require less crew to operate;
  - –Low-level platforms are served by trains with doors that are not automatic, requiring additional crew members for customer safety; and
  - –Length of platform. This is especially important with high-level platforms where train consist length exceeds platform length. Additional crew members may be required to ensure that only the doors of platformed cars open at such stations.

Measurable Data

Measurable data include the following:

- Station dwell times
- Time required for a revenue collection sweep
- Walking time through the cars
- Time to sell cash fares, collect tickets, issue seat checks
- Time allowances for required on-board railroad operating procedures.

APPLICATION OF EQUATIONS TO DETERMINE OPTIMUM TRAIN STAFFING

The train staffing formulas and select examples of its outputs are given here in Appendixes A and B, Tables 1 and 2, and Figures 1 and 2. Characteristics follow:

- Peak period
  - –Multiple-sweep formula on multizone local trains.
  - –Concentrate on a single fare sweep on zone express trains.
- Off-peak and weekends (Saturdays and Sundays treated as different data sets)
  - –Multiple-sweep formula on local portions of runs.
  - –Adapted peak-period sweep formula for the nonstop express portion of runs to and from the main terminal in the CBD (GCT on the Metro-North Commuter Railroad System).

INPUTS FOR DECISION-MAKING PROCESS IN DETERMINING ACTUAL TRAIN STAFFING

The output of the train staffing is used as an indicator of ideal train staffing levels. Additional input is provided by observations and reports by transportation management and supervisory staff, train crews, customer service inspectors, supervisory conductors, planning department supervisors, and passenger revenue accounting department reports.

The revenue protection survey is conducted jointly by the internal audit and the planning departments of Metro-North. This survey is performed annually to identify any specific

TABLE 1 Off-Peak Train Staffing Formulas A and B: Sample Using Saturday Train 9018

Columns	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	TRAIN NUMBER	CASH FARE TIME (mins.)	# CASH FARES	NON-CASH FARE TIME (mins.)	# OF NON-CASH	TIME TO WALK CAR (mins.)	# OF CAR IN TRAIN	RUNNING TIME (mins.)	STA.STOP TIME LOSS (mins.)	# OF STOPS	RECC. CREW	CURRENT CREW	GCT COUNTS	# OF WAY RIDER	TOTAL ON'S
UPPER	9018	0.41	156	0.095	60	0.5	6	42	1	12	2.62	2	194	22	216
LOWER	9018	0.41	8	0.095	378	0.5	6	21	1	3	1.87	2	374	12	386

TABLE 2 Peak-Period Train Staffing Formula: Sample Using Train 526 (a.m. Peak Period)

Columns	A	G	L	h	J	N		M	C	E	t	K
	TRAIN NUMBER	# CARS IN TRAIN	CURRENT CREW	LONGEST NON-STOP RUN TIME	# STOPS ENROUTE	INT. RIDERS	STOP AT 125 ST	GCT COUNTS	# CASH FARES	# OF NON-CASH FARES	TIME REQUIRED TO SWEEP (mins.)	RECC. CREW GCT
	526	10 m-1	2	35	1	0	N	1189	21	1168	49.74	1.84

NOTE: Column Designations Have Been Adjusted to Conform to the Column Letters Used in the Off-Peak Analysis.

SATURDAY,

Zone	TO NEW YORK	9018	9518	9020	9520
		AM	AM	AM	PM
UPPER ZONE	Brewster North	10 10		11 10	
	Brewster	10 13		11 13	
	Croton Falls	10 18		11 18	
	Purdy's	10 21		11 21	
	Golden's Bridge	10 24		11 24	
	Katonah	10 28		11 28	
	Bedford Hills	10 32		11 32	
	Mount Kisco	10 36		11 36	
	Chappaqua	10 41		11 41	
	Pleasantville	10 44		11 44	
	Hawthorne	10 48		11 48	
	Mt. Pleasant	10 50			
	Valhalla	10 52		11 52	
LOWER ZONE	North White Plains	10 56	11 03	11 56	12 03
	White Plains	11 00	11 07	12 00	12 07
	Hartsdale		11 10		12 10
	Scarsdale		11 13		12 13
	Crestwood		11 16		12 16
	Tuckahoe		11 18		12 18
	Bronxville		11 20		12 20
	Fleetwood		11 23		12 23
	Mount Vernon West		11 26		12 26
	Wakefield				
	Woodlawn				12 28
	Williams Bridge				12 30
	Botanical Garden		11 31		12 32
	Fordham		11 33		12 34
	Tremont				
	Melrose				
	125th Street	D11 26	11 41	D12 26	12 43
	Grand Central Terminal	11 37 AM	11 53 AM	12 37 PM	12 55 PM

FIGURE 1 Timetable, Saturday Train 9018 to New York.

MONDAY-FRIDAY

TO NEW YORK	MORNING PEAK 526	528	928	930	328	632
	AM	AM	AM	AM	AM	AM
Brewster North			7 13	7 23		
Brewster			7 16	7 26		
Croton Falls			7 21	7 31		
Purdy's			7 25	7 35		
Golden's Bridge			7 28	7 38		
Katonah			7 32	7 42		
Bedford Hills			7 36	7 46		
Mount Kisco			7 40	7 50		
Chappaqua			7 47	7 56		
Pleasantville			7 50			
Hawthorne			7 54			
Valhalla			7 58			
North White Plains		7 59	8 02			
White Plains		8 03	8 06			
Hartsdale	7 58					
Scarsdale	8 02					
Crestwood						8 20
Tuckahoe						8 22
Bronxville						8 25
Fleetwood					8 13	
Mount Vernon West			D8 16		8 18	
Wakefield						
Woodlawn					8 21	
Williams Bridge					8 23	
Botanical Garden					8 25	
Fordham					8 27	
Tremont						
Melrose						
125th Street			D8 29		D8 35	D8 41
Grand Central Terminal	8 37 AM	8 39 AM	8 43 AM	8 47 AM	8 49 AM	8 54 AM

FIGURE 2 Timetable, a.m. peak-period Train 526 to New York.

patterns of passenger revenue losses through missed fares. The survey also serves as a way to validate the output of the train staffing formulas.

All feedback is used to calibrate the computer models and ensure accuracy.

ADDITIONAL APPLICATIONS OF TRAIN STAFFING SIMULATIONS

The simulations are also used to test the train staffing sensitivity to ridership increases or decreases: the cost impacts of marketing and promotional programs are determined, and 1-day variances (Monday mornings, Friday afternoons, holidays, and special events) are measured. Also measured are the on-board impacts of tariff changes, off-train ticket sales by ticket offices and ticket-vending machines, and the introduction of new ticketing or fare collection technologies.

OFF-PEAK TRAIN STAFFING FORMULAS

As mentioned before, staffing levels on off-peak trains are determined by many factors. Through the organization of information on each off-peak train into Columns A through O as given in Table 1, a formula can be assembled that enables the optimum train staffing level to be determined. This equation is Formula A.

- Off-Peak Train Staffing Formula A

$$K = \frac{bc + de + 3fg}{h - ij}$$

where

- b = standard time to process a cash fare passenger, or 0.41 min;
- c = number of cash fares sold aboard train;
- d = standard time to process a noncash fare passenger, or 0.095 min;
- e = number of noncash fare passengers $= o - c$;
- 3 = standard of three fare collection sweeps by train crew;
- f = standard time for a crew member to walk one car length, or 0.5 min;
- g = number of cars in train;
- h = time allotted to crew for fare collection (running time);
- i = standard time loss by train crew at each station stop, or 1.0 min;

j = number of station stops made during fare collection;
K = recommended staffing for train;
l = current staffing levels;
m = ridership originating from or destined to GCT;
n = intermediate or way rider count; and
o = total number of passenger boardings (GCT and intermediate riders) = $m + n$.

Formula A is applicable for most off-peak trains that operate as multiple-stop locals for their entire runs. For the trains that operate as semiexpresses (making local stops over one portion of the line and operating as a nonstop express for the rest of the run to or from the CBD), a different formula is applied. The following equation reflects the one-time sweep manner in which train crews collect all remaining fares during the nonstop run to or from the CBD (GCT–New York).

- Off-Peak Train Staffing Formula B

$$K = \frac{bc + de}{h}$$

where variables are as given for Formula A.

Appendix A provides a sample calculation for Off-Peak Formulas A and B, and Table 1 provides a sample of the formula spreadsheet and output. The sample train used is Saturday Train 9018 from Brewster North to New York City; its timetable is shown in Figure 1. The upper zone refers to the local portion of the run between the outer terminus at Brewster North and an intermediate station at North White Plains, and the lower zone refers to the express run from North White Plains to GCT.

Many of the input requirements of Formulas A and B are met by data provided through the efforts of Metro-North's Planning Department and Passenger Revenue Accounting Department. The latter department provides the most recent cash fare volume data on a biannual basis. The Planning Department provides all passenger counts, train consist lengths, and timetable-related data. The Industrial Engineering Group of the Planning Department is responsible for developing the time standards used in the formulas.

Formula A is currently set so that the crew is able to perform three fare collection sweeps during the time allotted. Onboard observations of a select group of trains representative of all off-peak train schedule patterns revealed that the three-sweep rule for adequate revenue protection is valid on most off-peak, multiple fare zone, local trains. The only exceptions are some reverse-peak New Haven and Harlem Line local trains that stop at Fordham and Mount Vernon. On these trains, many riders that board at these two intermediate stations ride for only 10 to 20 min, making timely fare collection by the train crew more difficult than usual. As a result, reverse-peak trains are monitored closely via on-board observations to ensure that train staffing levels are adequate.

The running time (Column H) in Table 1 provides the total time available to the train crew to perform its fare collection sweeps. In general, it is set by the scheduled running time between specific station pairs that reflect where the formula expects the train crew to perform its fare collection sweeps.

The passenger count data in Columns M and N in Table 1 reflect the latest data collected by the Planning Department. For the relatively short-haul local trains on the Metro-North system from GCT–New York City to Croton-Harmon, North White Plains, and Stamford, the GCT passenger counts and intermediate ridership counts are directly applied to the staffing formula. Figure 3 provides a Metro-North system map to assist in reader orientation. GCT is the CBD, and the three aforementioned stations are intermediate stations on the Hudson, Harlem, and New Haven lines, respectively. A summary of this methodology is provided here:

- Inbound

Main count = number of passengers aboard at GCT

Way rider count = number getting off southward up to 125th Street

- Outbound

Main count = number of passengers aboard at GCT

Way rider count = number getting on from 125th Street and northward

For inbound trains from Brewster North and New Haven to New York, Formula A is used only for the outer portion of the run, where the train makes many local stops. To enable the formula to make the proper staffing recommendation for this part of the run, only data pertaining to the outer portion of the line are used.

For the nonstop express run as the train travels over the inner or lower portion of the line, Formula B is used to more accurately portray the one-sweep manner of fare collection by most train crews. Two separate staffing recommendations are made, one for the outer portion of the line and another for the inner zone portion of the trip. Through judicious use of step-on and step-off assistant conductors, additional crew cost savings can be realized as train crew sizes become tailored to meet the needs of specific line segments. The same methodology is applied in reverse for outbound trains from New York to Brewster or New Haven. It should be noted that this methodology cannot be applied in cases where the express portion of the run contains a few stops, as is the case with the Hudson Line.

Off-Peak Count Methodology for Trains To and From Brewster North

Harlem Line, Inbound

- Main count

upper = number getting on (Brewster North–Valhalla)

lower = number of passengers aboard at GCT

- Way rider count

upper = number getting off (Brewster–White Plains)

lower = number getting off (Hartsdale–125th Street)

METRO-NORTH'S SERVICE AREA

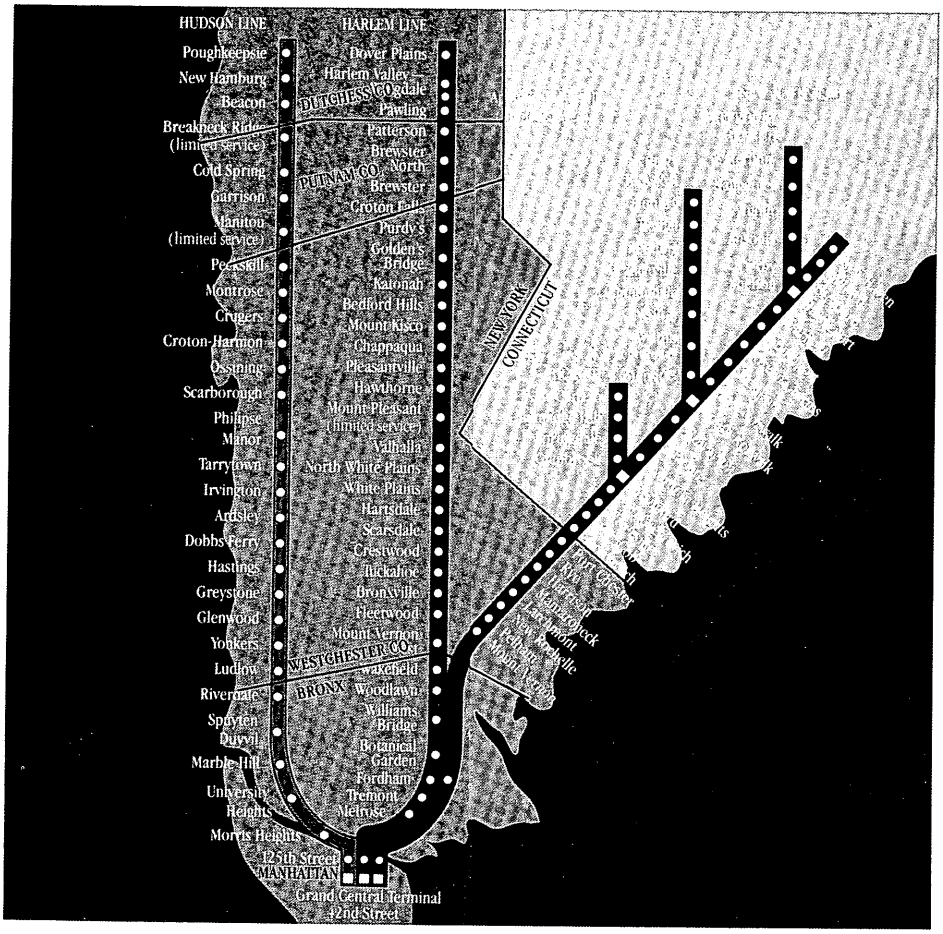

FIGURE 3 **Map of Metro-North service area.**

Harlem Line, Outbound

- Main count

lower = number of passengers aboard at GCT

- Way rider count

lower = number getting on (125th Street–Hartsdale)

upper = number getting on (White Plains–Brewster)

Off-Peak Count Methodology for Trains To and From New Haven

New Haven Line, Inbound

- Main count

outer = number getting on (New Haven–Noroton Heights)

inner = number of passengers at GCT

- Way rider count

outer = number getting off (Milford-Stamford)

inner = number getting off (Old Greenwich–125th Street)

New Haven Line, Outbound

- Main count

inner = number of passengers at GCT

- Way rider count

inner = number getting on (125th Street–Old Greenwich)

outer = number getting on (Stamford-Milford)

Off-Peak Count Methodology for Trains To and From Poughkeepsie

On the Hudson Line, Formula B cannot be applied to the through express trains in either direction to and from Poughkeepsie. This is because most of them are scheduled to make stops at Ossining, Tarrytown, Yonkers, and Marble Hill, providing an insufficient time for the single sweep assumed in Formula B. Therefore, two applications of Formula A are used to properly simulate the staffing requirements of both the upper and lower portions of the trip for all New York–Poughkeepsie trains.

Hudson Line, Inbound

- Main count

upper = number getting on (Poughkeepsie-Crugers)

lower = number of passengers aboard at GCT

- Way rider count

upper = number getting off (New Hamburg–Croton-Harmon)

lower = number getting off (Ossining–125th Street)

Hudson Line, Outbound

- Main count

lower = number of passengers aboard at GCT

- Way rider count

lower = number getting on (125th Street–Ossining)
upper = number getting on (Croton-Harmon–New Hamburg)

The Planning Department continuously updates the data used for the train staffing formula. The time standards used are periodically evaluated so that they are representative of actual conditions aboard the trains. When necessary, the formulas are reviewed to ensure that the staffing levels they recommend are indeed the actual staffing levels required to properly collect all fares.

PEAK-PERIOD TRAIN STAFFING FORMULA

For peak-period trains, the train staffing formula is much different. The criteria that directly affect the staffing recommendations made by the formula are GCT counts, number of cash fares, total time required for one fare collection sweep, and the longest nonstop running time near the CBD. Table 2 provides a sample of the formula worksheet and output. Again, information required for this study is organized in columns similar to those used for the off-peak period. For inbound peak-period trains, Metro-North requires that all ticket collection tasks be completed before a train's entry into the Park Avenue Tunnel. This is unique to this railroad as safety requirements dictate that a member of the train crew be present at each end of the train as it travels through this tunnel. The formula automatically adjusts the nonstop running time allotted to the crew so that they are finished with their fare collection sweep before the train's entry into the tunnel (8 min) if no stop is made at 125th Street. If a stop is scheduled at 125th Street, the formula calls for the train crew to complete the fare collection task 2 min before arrival at this station, where many customers disembark. For all outbound trains, the formula calls for the crew to be finished 2 min before arriving at its first stop.

This peak-period staffing formula portrays limited-stop zone expresses. It can only approximate the staffing requirements of multiple-stop local trains, and on-board observations supplement the recommendations of the formula.

The peak-period methodology for staffing trains is described:

1. Determine t, the amount of time required for a fare collection sweep.

$$t = \frac{\text{number of noncash fares}}{28.4} + (0.41 \times \text{number of cash fares})$$

2. Determine the staffing level K, by comparing t against h, the total available time for the fare collection sweep.

–All outbound and inbound trains stopping at 125th Street:

$$K = \frac{t}{h - 2\text{ min}}$$

–Inbound trains not stopping at 125th Street:

$$K = \frac{t}{h - 8\text{ min}}$$

Appendix B provides a sample calculation using a.m. peak-period Train 526.

APPENDIX A
Sample Calculation for Off-Peak Period

The following sample uses Train 9018, the Saturday inbound train from Brewster North to GCT (timetable displayed in Figure 1).

UPPER ZONE: OFF-PEAK FORMULA A

$$K = \frac{bc + de + 3fg}{h - ij} = \frac{(0.41)(156) + (0.095)(60) + 3(0.5)(6)}{42 - (1)(12)} = 2.62$$

where

$b = 0.41$,
$c = 156$,
$d = 0.095$,
$e = 60$,
$f = 0.5$,
$g = 6$,

h = 42,
i = 1,
j = 12, and
K = recommended crew for upper zone of Train 9018.

LOWER ZONE: OFF-PEAK FORMULA B

$$K = \frac{0.095e + 0.41c}{h} = \frac{(0.095)(378) + (0.41)(8)}{21} = 1.87$$

where

c = 8,
e = 378,
h = 21, and
K = recommended crew for lower zone of Train 9018.

APPENDIX B
Sample Calculation for Peak Period

Train 526, the morning peak-period zone express from Hartsdale/Scarsdale to New York City, is used for this sample. This train does not stop at 125th Street (timetable displayed in Figure 2).

1. Determine the value of t, the time required for a fare collection sweep.

$$t = \frac{\text{number of noncash fares}}{28.4} + (0.41 \times \text{number of cash fares})$$

$$= \frac{1189 - 21}{28.4} + (0.41)(21)$$

$$= \frac{1168}{28.4} + 8.61$$

$$= 41.13 + 8.61 = 49.74 \text{ min}$$

2. Determine the train crew size required.

$$K = \frac{t}{\text{longest nonstop running time} - 8 \text{ min}}$$

$$= \frac{49.74 \text{ min}}{35 - 8 \text{ min}} = 1.84$$

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Development of Cost-Effective Sampling Plans for Section 15 and Operational Planning Ride Checks: Case Study for Madison, Wisconsin

WEN-JING HUANG AND ROBERT L. SMITH, JR.

More cost-effective procedures for Section 15 ride check sampling are developed and integrated with the overall planning and operations analysis data needs of Madison Metro, a medium-sized bus system serving Madison, Wisconsin. To develop and test alternative sampling plans, data from three primary sources were used: daily electronic farebox passenger counts, 100 percent ride checks for an "equivalent weekday," and Section 15 sample data for 2 years. Analysis of the primary data suggested that a boardings-based ratio estimate of passenger miles with stratification by week with round trips as the sample unit provides the most cost-effective Section 15 sampling plan. For Madison Metro a sample of only two round trips per week will meet the 10 percent precision requirement. Extension of the sampling plan for operational planning is possible by expanding the sample unit to two consecutive round trips. The resulting expanded sampling plan would update the equivalent weekday ride check data base in only 3 years.

The Madison Metro transit system is a medium-sized bus system serving a population of 244,000 in the Madison, Wisconsin, urban area. In 1990 Madison Metro ran 118 peak-hour buses on 5 primary and 15 secondary, circulator, and express routes attracting 32,000 passengers per weekday and 9,900,000 a year. In response to downward ridership trends, Madison Metro contracted with a consultant for a comprehensive operations analysis (COA) study that was conducted in the spring of 1990 (*1*). The data collected in the COA included a 100 percent ride check of all vehicle (bus) trips for an "equivalent weekday." The ride check data were used extensively in the comprehensive route restructuring that was implemented in the fall of 1990.

Because the COA (100 percent ridecheck) data were found to be so useful, Madison Metro would like to keep the COA data base up to date through a modest expansion of its current field data collection program. Currently, the Section 15 ride check data collection required by FTA is conducted independent of other field data collection and is not used by Madison Metro for system monitoring or planning. One possibility for reducing the costs of maintaining the COA data base would be to integrate the COA ride check updates with the Section 15 data collection requirements.

The purposes of this research are (a) to develop more cost-effective Section 15 ride check sampling procedures and (b) to determine if Section 15 and COA update data collection can be integrated effectively. The ordering of the purposes with the initial focus on Section 15 is deliberate. The FTA Section 15 samples must be random and distributed throughout the year. Because of the difficulties and cost of scheduling manual ride checks to cover all days of the week and all service hours, the first priority should be to minimize the Section 15 sample requirements. In contrast, the COA update need not be based on random samples. In fact, a highly systematic 100 percent data collection effort may give more useful data.

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PRIOR RESEARCH

The *Bus Transit Monitoring Manual* provides the most comprehensive consideration of field collection of bus system operating data (*2*). The report recommends a route-level two-stage cluster sampling plan for collecting both ride check and point check data. Route-level data are then aggregated to meet Section 15 requirements. Preliminary samples (pretest) are proposed to estimate data variation, which is used to identify the primary survey sample size requirements. The methodology is not designed to generate 100 percent COA ride check data.

Damm surveyed 30 U.S. transit systems to determine their information needs for transit management and their interest in computer-aided tools (*3*). Review of Section 15 data collection efforts revealed that these data are not often used by transit managers. Some systems, however, have integrated Section 15 into their overall operating data collection program with data disaggregated by route and time of day.

McGrath et al. reviewed several innovative Section 15 sampling plans, both actual and proposed (*4*). The review led to general suggestions for reducing Section 15 sampling requirements by tailoring stratified sampling and cluster sampling techniques to the operating conditions of individual transit systems. The authors recommended use of actual Section 15 ride check data for the design of improved sampling strategies.

In a 1983 study funded by FTA, Smith conducted an inventory of the Section 15 sampling procedures used by 58 of the largest U.S. transit systems (*5*). A wide range of sampling methods was found including many nonstandard methodologies. Detailed analysis of alternative sampling plans for several transit systems revealed many opportunities for reducing the sample size required to obtain a precision of 10 percent. The potential for a dramatic reduction in sample size on the basis of a ratio estimate of passenger miles per passenger was demonstrated using actual Section 15 data for Madison Metro. The ratio estimate, however, requires an independent estimate or actual count of total passengers.

The *Bus Transit Monitoring Manual* was updated in 1985 and published as the *Transit Data Collection Design Manual* (*6*). The design manual included sampling methods for using ratio estimates to reduce sample size requirements. The statistical basis for using ratio estimates was documented in a 1987 paper by Furth and McCollom (*7*). Using a ratio estimate of boardings to revenue for the Pittsburgh transit system, they found that the Section 15 sample size could be reduced to 149, whereas a ratio estimate of passenger miles to revenue required a sample size of only 129.

In a 1988 paper Furth et al. evaluated several cluster sampling techniques for collecting Section 15 ride check data that would make the data more useful for operational planning purposes (*8*). Both ratio estimates and stratification were incorporated into the sampling alternatives and tested using data from the Southern California Rapid Transit District (SCRTD). The SCRTD data present a particular challenge because SCRTD did not have registering fareboxes and the drivers did not count passengers. The relatively simple stratified ratio-to-cluster-size sampling strategy was the optimum for SCRTD requiring only 38 half-runs (clusters of bus vehicle trips) to meet Section 15 precision requirements. The usefulness of the resulting Section 15 data base for other purposes was not discussed in the paper.

FTA SECTION 15 SAMPLING REQUIREMENTS

The first Section 15 sampling plan was documented by UMTA Circular 2710.1, which specifies a two-stage cluster sample based on a systematic sample of days followed by a random sample of one-way bus trips within each sample day (*9*). The formula for the relative variance (coefficient of variation squared) of passenger miles per one-way trip is

$$CV_{PM}^2 = \frac{N-n}{N}\frac{CV_b^2}{n} + \frac{M-m}{M}\frac{CV_w^2}{mn} \tag{1}$$

where

CV_b^2 = between-day relative variances,
CV_w^2 = within-day relative variances,
n = number of sample days,
N = number of population days,
m = number of one-way trips per day in sample, and
M = number of one-way trips per day in population (*10*).

Note that the number of one-way bus trips per day in the population is assumed to be constant. Thus, variation in service between weekends and weekdays is not accounted for, but since m is much less than M, the ratio $(M - m)/M$ is essentially equal to 1. Thus, the assumption of constant M is reasonable. The minimum sample size under Circular 2710.1 is 549 trips on the basis of sampling three trips every other day (n = 183, m = 3). This sampling plan was based on the Wells memorandum (*11*), which assumed that $CV_b^2 = 0.1$ (or $CV_b = 0.316$) and $CV_w^2 = 1.0$, so that for the 95 percent confidence level the precision, r, is

$$r = t_{.025549} \times CV_{PM} = 1.96 \times 0.0458 = 0.090 \tag{2}$$

Because many transit systems found the requirement for sampling 549 trips per year burdensome, UMTA developed an alternative revenue-based sampling procedure, UMTA Circular 2710.4, that requires a sample of only 208 trips (*12*). The key to the smaller sample size is the use of a ratio estimate. Total annual passenger miles are estimated on the basis of the sample estimate of the ratio of passenger miles to farebox revenue multiplied by the actual farebox revenue for the year. For a simple random sample (SRS) the relative variance of a ratio estimate of passenger miles (PM_R) is given by

$$CV_{P\hat{M}_R} = \frac{\left(1 - \frac{n}{N}\right)}{n} \times (CV_{PM}^2 + CV_{REV}^2 - 2\rho CV_{PM}\, CV_{REV}) \tag{3}$$

where

CV_{PM} = coefficients of variation for passenger miles,
CV_{REV} = coefficients of variation for revenue,
ρ = simple correlation between passenger miles and revenue,
n = sample size, and
N = population size.

For any sample observation i the passenger miles are estimated as

$$P\hat{M}_i = \hat{R} \times REV_i \tag{4}$$

where $\hat{R}$ equals $\overline{PM}/\overline{REV}$ from the sample.

The Circular 2710.4 sampling procedure, however, is not an SRS from the entire year; instead, the sample is stratified by week and an SRS of four one-way trips is selected each week. This complicates the precise estimate of the variance of the ratio estimate. It can be argued that stratification is likely to increase the precision of the estimate of passenger miles. Thus, Equation 3 can be used as an upper bound on the precision of the ratio estimate. The same basic equations are also used to estimate total annual passengers (boardings) from a ratio estimate of boardings to revenue.

One complication associated with the revenue-based ratio estimate is that if the fare changes, the correlation between revenue and passenger miles will be reduced so that the required level of precision may not be achieved. The solution specified in Circular 2710.4 is to make separate ratio estimates for each fare period. To compensate in part for the smaller sample size in each fare period, the sample size is increased to five trips per week for 12 weeks following the fare change.

An additional problem with the revenue-based ratio estimate is that if there is substantial use of passes or tickets, then the correlation between revenue and passenger miles or passengers is likely to be low, thus reducing the precision of the ratio estimate. This problem is avoided by using a passenger-based ratio estimate where passenger miles are estimated from the ratio between passenger miles and passengers. Only transit systems with an independent tabulation of passengers can use this method.

Transit systems that could take advantage of improved sampling strategies such as the passenger-based ratio estimate no longer need explicit FTA approval. Instead, the transit systems need only self-certify the methodology on the basis of analysis by a qualified statistician.

MAJOR DATA SOURCES

Three major data sets were available to this study from data collected by Madison Metro:

- 1990 and 1991 electronic farebox (EFB) summary data;
- 100 percent ride check data for an equivalent weekday collected in the spring of 1990 as part of the COA study; and
- 1989 and 1990 Section 15 ride check data.

The 1990 and 1991 EFB summary data provided the total daily ridership recorded by the EFBs and tabulated by computer. The EFB passenger data included for each bus trip segment the starting and ending times, the number of passengers by passenger type, and revenue generated. The detailed review of the EFB data showed that some bus operators did not fully follow the EFB operating rules that required them to register passenger data at designated checkpoints. Consequently, bus trip segment-level ridership could not be identified for all bus trip segments. Besides driver error, errors in the EFB data could be traced to internal EFB clock timing, mechanical, and data storage failures. These problems, in general, did not affect the reliability of the total daily ridership counts. Thus, variation in ridership from day to day could be analyzed, but variation within days could be made only after manual editing of the data.

Madison Metro's COA ride check data were collected in the spring of 1990 for 100 percent of the bus trips on an equivalent weekday. If the ride checks for a route could not be completed on a single weekday, then the remaining ride checks were collected on the same day in the following week. All of the ride checks for the entire system were completed in about 3 weeks.

For Section 15 ride checks until 1989, Madison Metro followed the standard Wells two-stage cluster sampling procedure by sampling three one-way bus trips every other day. Most of Madison Metro's one-way bus trips are "through-routed" and composed of two bus trip segments: inbound to the central business district (CBD) and outbound in the same direction from the CBD. In 1989 Madison Metro switched to the revenue-based ratio estimate sampling procedure and began using segments as the sampling unit. Madison Metro sampled an average of nine segments a week in 1989 and reduced the rate to the minimum Section 15 requirement of four segments a week in 1990.

PRELIMINARY DATA ANALYSIS

To identify Section 15 sampling strategies that may be more cost-effective than the existing standard options (Wells two-stage cluster or revenue-based ratio estimate), data on the inherent variability of passengers (boardings), passenger miles, and revenue are needed. Fortunately, much, but not all, of the required information can be obtained from the three data sources described earlier. Analysis of the total daily ridership from the EFB data for 1990 and 1991 is presented in Table 1. As expected, the average daily passengers on a Saturday or Sunday is only a third to a sixth the average for a weekday. The relative amount of variation "between days" is given by the coefficient of variation (*CV*) defined as the standard deviation divided by the mean. For all days the *CV* is about 0.5, but weekdays are more homogeneous, with *CV*s of about 0.2, and Saturdays and Sundays are even more homogeneous, with *CV*s in the range of 0.1 to 0.2. As shown in Figure 1, the average daily ridership by month varies substantially over the year. The summer months' ridership is about a third lower than the peak months. The between-day *CV*s by month, however, are relatively constant—in the range of 0.45 to 0.55—except for December.

The major reduction in *CV* for stratification by day of week suggests that the sample size for the Wells two-stage cluster sample could be reduced by stratification by day of the week since Wells assumed a between-day *CV* of 0.316. Information on the other component of variation that is required for the Wells sample, the within-day *CV*, is available, in part, from the COA ride check data. One other possible stratification is summer versus nonsummer days, particularly for weekdays.

The COA ride check data provide an estimate of within-day variation for weekdays. As given in Table 2, the *CV*s for boardings (passengers) and passenger miles are heavily dependent on the level of aggregation. The greatest amount of variation occurs at the segment level. Considerably less variation is found for one-way trips because a segment inbound to the CBD is combined with a segment outbound from the CBD. Particularly in the peak hours, low passenger volume in one direction will be balanced by higher volume in the other. Additional smoothing occurs in moving to the round trip and vehicle block levels. The *CV* data for passenger miles clearly indicate that collection of Section 15 ride check data at higher levels of aggregation will permit reduction of the

TABLE 1 Madison Metro Daily Passengers by Day of Week

1990	N	MEAN	STDEV	CV[a]	1991	N	MEAN	STDEV	CV[a]
SUN	51	5452	708	0.103	SUN	51	5986	987	0.165
WEK	255	32546	7477	0.230	WEK	255	33325	7348	0.220
SAT	52	9686	1572	0.162	SAT	52	10978	2156	0.196
HOL	7	2820	903	0.320	HOL	7	3270	1078	0.329
ALL	365	24933	13260	0.532	ALL	365	25745	13202	0.513

Note: <SUN> = Sundays; <WEK> = Weekdays; <SAT> = Saturdays; and <HOL> = Holidays.

[a] Coefficient of Variation (CV) = Standard Deviation/Mean

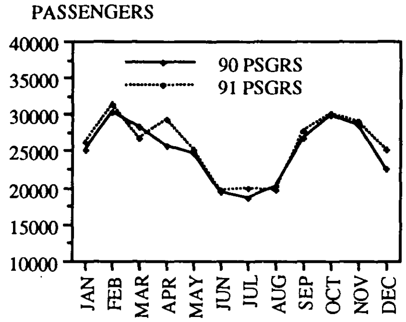

FIGURE 1 Average daily passengers by month for 1990 and 1991 from EFB data.

sample size for the Wells two-stage cluster sample. Partial Section 15 data from 1982 are also presented in Table 2 for comparison with the COA data. The Section 15 data represent one-way trips for all days rather than just weekdays. The all-days *CV*s should be somewhat higher than the *CV*s for the COA one-way trips, which is in fact the case.

Two other data items are of interest in Table 2. First, the relative variation in passenger miles compared with boardings computed as CV_{PM}/CV_B is of interest since the *CV* for passenger miles can then be estimated if the *CV* for boardings is available. This is significant since data on boardings are more generally available than data on passenger miles. As shown in Table 2, the *CV* for passenger miles ranges from 3 to 15 percent higher than the *CV* for boardings. Thus, to achieve the same precision, sample sizes for estimating passenger miles must be slightly higher than those for estimating only boardings.

Second, the correlation between passenger miles and boardings is of interest for ratio estimates. Since a 100 percent count of boardings is available from the EFB data in Madison, passenger miles can be estimated from a ratio estimate of passenger miles to boardings. A high correlation between passenger miles and boardings reduces the sample size requirements dramatically. Thus, for maximum reduction in sample size, Section 15 samples should be based on round trips or even vehicle blocks.

As discussed earlier, the 1989 and 1990 Section 15 ride check data collected by Madison Metro were nominally based on random samples of one-way trip segments with stratification by week. As shown in Table 3, the sample size was 470 (or about 9 segments per week) for 1989 and 199 (or about 4 segments per week) in 1990. The amount of variation in boardings and passenger miles is about the same for both years, with the *CV* for passenger miles ranging from 15 to 17 percent higher than the *CV* for boardings. Also, the *CV* are consistent with the COA *CV* at the segment level (see Table 2). In contrast, the correlation coefficients given in Table 3 are closer to the COA correlation coefficient for the one-way trip level, but much smaller than the 1982 correlation coefficient for Section 15 one-way trips ($\rho = 0.916$; see Table 2).

One final observation on the Section 15 data in Table 3 is that the overall ratio of passenger miles to boardings for 1989 is substantially higher than for 1990 (3.96 versus 2.85). Since the mean passenger miles are almost the same for both years, the difference in the ratios is the result of lower boardings for 1989 than for 1990. Subsequent stratification of the Section 15 data by month showed that the monthly ratios of passenger miles to boardings were quite constant throughout each year. One possible explanation for the observed systematic difference in the passenger miles per boarding ratio between 1989 and 1990 would be a difference in how passengers on board at the start of a ride check were tabulated. Fortunately, the observed systematic difference does not affect the validity of the evaluation of alternative sampling plans that is the focus of this paper.

EVALUATION OF ALTERNATIVE SAMPLING PLANS

Overview

The starting point for the development of more cost-effective Section 15 sampling plans is the evaluation of the precision of the Section 15 data collected by Madison Metro in 1989 and 1990. Although the nominal sampling plan for both 1989 and 1990 was a stratified random sample with a fixed number of segment samples to be selected randomly from each week, the number of trips actually sampled per week varied substantially. The deviations from the fixed sampling plan were taken into account in computing the actual precision of the stratified sample and the two-stage cluster sample that resulted from the 1989 and 1990 Section 15 data. For the purposes of computing the precision of an equivalent SRS, however, the Section 15 data were treated as if the samples were an SRS.

TABLE 2 Summary of COA Ride Check and 1982 Section 15 Data by Level of Aggregation

Type of Information	Bus Trip Segment	One-Way Trip	Round Trip[a]	Vehicle Block	One-way Trip (1982)[b]
Boardings	18.1	35.8	76.2	421.1	43.8
Psgr. miles	64.7	127.4	291.3	1595	157
Boarding CV	0.774	0.543	0.418	0.401	0.61
Psgr. miles CV	0.797	0.603	0.460	0.429	0.70
Ratio CV_{PM}/CV_B	1.030	1.110	1.100	1.070	1.148
Correlation[c]	0.655	0.788	0.886	0.940	0.916

[a]Based on five main routes; A, B, C, E, & J.
[b]Section 15 ride check data for 183 observations in the first part of 1982.
[c]Correlation between boardings and passenger miles, $\rho_{B,PM}$

TABLE 3 1989 and 1990 Section 15 Data Summary

Data Item	N	MEAN	STDEV	CV	CORR[b]
1989 Boardings	470	15.6	10.8	0.693	0.726
1989 Passenger Miles	470	61.7	50.0	0.810	--
Ratio PM/B (1989)	--	3.96	--	1.169[a]	--
1990 Revenue	199	4.60	4.28	0.930	0.692
1990 Boardings	199	21.1	14.5	0.707	0.783
1990 Passenger	199	60.2	48.8	0.810	--
Ratio PM/B (1990)	--	2.85	--	1.146[a]	--

[a]Ratio of CV_{PM}/CV_B.
[b]Correlation with passenger miles.

Estimates of the precision at the 95 percent confidence level of sample estimates of average passenger miles per segment for three basic sampling methodologies are presented in Table 4; these results are given initially without detailed explanation of how the estimates of precision were computed. The focus in Table 4 is on the extent to which differences in precision are possible for alternative sampling methodologies given the same data sets. The simplest sampling methodology, SRS, is shown first for comparison with the two FTA-recommended methodologies, stratification by week, and two-stage clusters (sample days first, then bus trip segments within sample days). The precision of ratio estimates based on the ratio of passenger miles to boardings is also shown for each of the sampling plans.

As given in Table 4, the Madison Metro Section 15 data for 1989 meet the required precision of 0.10 (10 percent) under all three sampling plans. Stratification by week provides almost the same level of precision as the SRS, whereas the two-stage cluster precision is substantially lower (higher numerical value). Because of the high overall correlation between passenger miles and boardings ($\rho = 0.726$), the ratio estimate improves the precision of all three sampling plans substantially.

For the 1990 Section 15 data in Table 4, the same basic patterns as for 1989 exist; however, primarily because of the lower sample size (199 versus 470), the precision of the sample is much lower. In fact, none of the basic sampling plans meets the 10 percent precision requirement; however, all of the ratio estimates based on boardings have a precision of less than 10 percent. For 1990, sample revenue data were also available. The precision of the ratio estimate based on the ratio of passenger miles to farebox revenue is much lower than for the boardings-based ratio estimate. This is explained by the lower correlation between passenger miles and revenue, which is the result of substantial pass use by Madison Metro passengers.

Selection of the most cost-effective sampling methodology from among the alternatives considered in Table 4 requires consideration of both the administrative difficulties of sample selection, data collection, and data processing and the potential for cost savings through reductions in sample size that are possible when the precision exceeds the 10 percent level. In general, the SRS requires slightly more administrative effort for sample selection and the staffing requirements will be slightly more variable than with stratification by week. At least for the Madison Metro data, the simplicity of stratification by week more than offsets the small reduction in sample size that may be possible with an SRS.

Because Madison Metro has an independent estimate of boardings (100 percent passenger count), it can take advantage of the substantial increase in precision provided by the boardings-based ratio estimates. Again, stratification by week

TABLE 4 Precision of 1989 and 1990 Section 15 Sample Estimates of Passenger Miles at 95 Percent Level

Assumed Sampling Methodology[a]	Precision (r) 1989	1990
No Stratification		
- Simple Random Sample (Sample Size-n)	0.0732 (470)	0.113 (199)
- Ratio Estimate for a Simple Random Sample[b]	0.0509	0.0708
Stratification by Week		
- Simple Random Sample	0.0763	0.127
- Ratio Estimate (Psgr. Miles/Boardings)	0.0583	0.0816
- Ratio Estimate (Psgr. Miles/Revenue)	--	0.108
Two-Stage Cluster		
- Standard Wells	0.0916	0.127
- Ratio Estimate[b]	0.0654	0.080

[a]Based on bus trip segment level sample
[b]Ratio estimate based on Passenger Miles/Boardings

appears to provide the best combination of administrative simplicity and precision.

The two-stage cluster sample has the advantage that the days for which staff must be assigned for data collection follow a regular pattern. In contrast, with stratification by week, the days sampled will vary from week to week. Also, the two-stage data collection is concentrated in somewhat fewer days, which may be easier to staff. One problem here is that more than one checker may be required for a few days in which sample trips overlap.

Stratification by Week

To identify possible improvements to the stratification-by-week sampling methodology, it is helpful to identify how the sample variance, $s^2(\bar{y}_{ST})$, for a stratified random sample can be computed. If the finite population correction factor is ignored, then

$$s^2(\bar{y}_{ST}) = \sum_{h=1}^{L} \frac{W_h^2 s_h^2}{n_h} \tag{5}$$

where

$W_h = N_h/N$ = stratum weight,
s_h^2 = stratum sample variance, and
n_h = sample size for hth strata.

The variance of $\bar{y}_{ST}$ thus is the sum of the variances of the individual strata sample means weighted by the relative size of the stratum squared. The precision of the sample can be increased by reducing the stratum sample variance, which can most easily be done by aggregating the sample from one-way segments to round trips. For stratification by week a major part of the stratum variance is within-day variance. The COA data presented in Table 2 can be used to determine the impact of aggregation from segments to round trips on within-day variance. For a given precision the CV^2 are proportional to the required sample size. Thus, an initial estimate of the reduction in sample size from sampling round trips is given in Table 2 as

$$[CV_{PM}(\text{round trip})/CV_{PM}\ (\text{one-way segment})]^2 = (0.460/0.797)^2 = 0.577^2 = 0.33 \tag{6}$$

Thus, the impact of aggregation on reducing the required sample size is likely to be substantial.

As demonstrated in Table 4, the impact of the ratio estimate on the precision of the stratified sample was substantial for the segment-level trip sample. The sample variance for the ratio estimate is calculated by substituting d_{hi}, the error from using the ratio estimate, in place of the sample value, y_{hi} (passenger miles), in the strata variance formula (Equation 5) where

$$d_{hi} = y_{hi} - Rx_{hi} \tag{7}$$

$$x_{hi} = \text{auxiliary variable (boardings)} \tag{8}$$

$$R = \sum_{h=1}^{L} \sum_{i=1}^{n_h} y_{hi} \Big/ \sum_{h=1}^{L} \sum_{i=1}^{n_h} x_{hi} \tag{9}$$

Equation 7 was applied to the Section 15 data to generate the ratio estimates for stratification by week that are presented in Table 4. Section 15 data for higher levels of aggregation (one-way trip and round trip levels) were not available to permit the direct calculation of the precision of ratio estimates as a function of aggregation level. Consequently, the ratio estimate for an SRS was used to examine the impact of aggregation. The results are presented in Table 5.

As shown previously in Equation 3, the variance of a ratio estimate for an SRS is a simple function of the *CV*s of the two variables used for the ratio, the correlation between the variables, and the sample size. To obtain a conservative estimate of the impact of aggregation on precision, the results given in Table 5 are based on the one-way segment CV_{PM} and CV_B from the Section 15 data. The estimate of correlation between passenger miles and boardings (passengers) was taken from the COA data (see Table 2). Although the COA data represent only within-day variance, the correlation for the one-way segment level ($\rho = 0.655$) is lower than either of the correlations for the Section 15 data ($\rho = 0.726$ for 1989, $\rho = 0.783$ for 1990), which represent the correlation over the entire year. Thus, the COA data probably understate the increase in precision (lower r) that results from the higher levels of aggregation.

Since Section 15 requires a precision of only 10 percent ($r = 0.10$), the increase in precision resulting from aggregation can be translated into smaller minimum sample sizes that will still achieve the 10 percent precision level. As pre-

TABLE 5 Estimate of Precision and Minimum Sample Size for SRS Ratio Estimate as Function of Level of Aggregation

Level of Aggregation of Sample	COA Corr.[a] (ρ)	1989 Section 15[d] Precision[b] (r)	1989 Section 15[d] n_{min}[c]	1990 Section 15[d] Precision[b] (r)	1990 Section 15[d] n_{min}[c]
Bus Trip Segment	0.655	0.057	152	0.089	156
One-way Trip	0.788	0.045	95	0.070	97
Round Trip	0.886	0.033	53	0.052	55
Vehicle Block	0.940	0.025	30	0.039	31

[a]Correlation between passenger miles and boardings (passengers obtained from 100 percent ride check equivalent weekday COA data).
[b]Based on Equation 2 and 3.
[c]Minimum sample size required to achieve $r = 0.10$ given by $n_{min} = n^*(r/0.1)^2$
[d]See Table 3 for CV_{PM} and CV_B.

sented in Table 5, the minimum sample sizes decline to very modest levels of 53 to 55 at the round-trip level of aggregation. The minimum sample sizes are remarkably consistent between the 1989 and 1990 Section 15 data. The results in Table 5 can be extrapolated to the ratio estimate for stratification by week with some confidence since the precision of that sample for 1989 and 1990 (see Table 4) that is at the segment level, is almost the same as those shown in Table 5 that are at the segment level.

On the basis of Table 5, the best sampling plan for stratification by week involves sampling two round trips each week, for 104 round trips per year. The sample would have a wide margin of error built in since 104 one-way trips would also just barely satisfy the precision requirements for a sample of two one-way trips per week. Sampling at least two trips a week is needed in order to compute the individual strata variances and thus verify the precision of the sample.

Consideration of the cost-effectiveness of the proposed sample of 104 round trips a year must include both the actual staff costs for data collection and processing and the value of the information obtained compared with the present sample of 208 bus trip segments. Since the bus trip segments, in fact, require a return segment, the 208 segments are equivalent to about 104 round trips in terms of staff time spent on the bus. The 208 segments, however, require about twice as much nonproductive travel time to reach the starting point for the on-board data collection. Thus, we expect that the proposed sample of 104 round trips will actually require less total checker staff time than is being spent on the 208 segments. The 104 round trips will have the added benefit of reducing by about 50 percent the number of times that staff must be assigned to work outside of normal business hours. Also, total overtime hours should decrease because of the reduction in total travel time. On the basis of extrapolation from Table 5, the precision of the proposed sample size should be about 7 percent, which is in the middle of the range of precision between the 1989 and 1990 Section 15 samples. Finally, the 104 round trips will provide four times as much ride check data and provide a more useful starting point for a more comprehensive ride check data collection program. On balance, then, the proposed sample of 104 round trips is clearly cost-effective. It will provide much more useful data at a higher level of precision and should actually cost less to collect than the 1990 Section 15 sampling plan.

Two-Stage Cluster Sample

The two primary means of increasing the precision of the two-stage cluster samples, use of a ratio estimate and aggregation of the sample unit, were evaluated in detail using the available Madison Metro data. As was shown in Table 4, the boardings-based ratio estimate increases the precision of the two-stage cluster sample estimate of passenger miles quite substantially in the range of 29 to 37 percent. Increasing the level of aggregation to the round-trip level results in a somewhat smaller but still substantial improvement in precision ranging from 14 to 19 percent. The smallest sample resulting from the combined impact of both the ratio estimate and the round trip level of aggregation is estimated to be 98 to 144 with no margin of error. This is about twice or three times the sample size found for the SRS ratio estimate (see Table 5). Consequently, unless the regular pattern of days sampled (every fourth day, every fifth day, etc.) is required for administrative reasons, the SRS sampling plan and by extension the stratification by week sampling plan should be a better alternative.

INTEGRATION OF SECTION 15 AND COA

The update of the COA 100 percent ride check data for an equivalent weekday will be most useful if all of the data are collected over as short a period as possible. As long as ridership is not changing rapidly, a period of 1 to 3 years should still provide useful data. The data can most efficiently be collected in large groups of trips made by the same vehicle. Thus, unproductive travel time by the checkers will be minimized.

To use the proposed Section 15 sampling plan (stratification by week with an SRS of two round trips selected from each week) as the foundation of the COA update, a minor modification is needed. The sample is stratified by week, but for each week the round trips are sampled without replacement of any trips previously sampled for that year or series of years until all equivalent weekday trips have been sampled. The resulting sample should produce an unbiased estimate of passenger miles with a smaller variance than the SRS alternative since more information is being obtained.

One alternative for the Section 15 sampling plan is to sample pairs of round trips. For Madison Metro, sampling pairs of round trips would provide ride check data on more than a third (37 percent) of the equivalent weekday trips each year. Furthermore, with a 50 percent increase in the sampling rate (to three pairs of round trips per week) fully 50 percent of the equivalent weekday trips could be sampled annually, 100 percent over 2 years. Furthermore, the sample rate can be varied from week to week as long as the base rate of two trips a week is maintained.

SUMMARY AND CONCLUSIONS

Both of the standard FTA Section 15 sampling methodologies, the two-stage cluster sample and the revenue-based ratio estimate with stratification by week, were evaluated in detail. The primary alternative sampling strategies evaluated were use of passenger-based ratio estimates and increase in aggregation for the sample unit (moving from bus trip segment to one-way trip to round trip).

Because of the high correlation between passenger miles and passengers, the ratio estimate substantially increases the precision of both sampling plans. Increasing the level of aggregation of the sample unit, using one-way trips or round trips, also increases the correlation between passenger miles and passengers and consequently increases the precision of the ratio estimate. These results confirm the work of Furth and his colleagues on ratio estimates and cluster sampling. For an SRS of round trips, a 10 percent precision is achieved with only 53 to 55 trips per year. A similar sample size should also be adequate for stratification by week. Consequently, allowing for a substantial margin of error, the recommended Section 15 sampling plan is for a ratio estimate with stratification by week and a random sample of two round trips each week, resulting in a total sample size of 104 round trips per year. This sampling plan is highly cost-effective since four times as much data are obtained with a slightly smaller level of checking staff effort.

Extension of the recommended Section 15 sampling plan to update the COA 100 percent equivalent weekday ride check data requires sampling without replacement from equivalent weekdays. With an increase in the sample size to three pairs of round trips per week, the COA data could be updated in only 2 years.

Madison Metro currently allocates about 20 percent of one person's time annually (20 percent FTE) for Section 15 field data collection. With the base round-trip sampling plan recommended here, somewhat less time would be required, perhaps 17 percent FTE. With the pair of round trips sampling option, the field data collection should still require less than 30 percent FTE and would result in a fully updated COA data base in only 3 years. Thus, by allocating only an additional 10 percent FTE annually, the costly periodic intensive update of the COA data base is avoided. The stream of ride check data from the more intensive Section 15 sampling plan is potentially more useful than the periodic COA update since trends over time can be monitored more directly.

The sampling methodology proposed for Madison Metro should also apply to any transit system that has an accurate independent count of annual passengers. Existing Section 15 ride check data can easily be used to estimate the expected precision of the passenger-based ratio estimate. With the sample size reduced to only two round trips per week, Section 15 data collection should not be a burden to any transit system. In addition, by collecting round trips for equivalent weekdays the Section 15 ride check data become useful for operations planning.

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Ridership Sampling for Barrier-Free Light Rail

PETER G. FURTH AND ASHOK KUMAR

The challenges and current practice in ridership estimation on light rail lines, particularly barrier-free lines, are reviewed. Two-stage sampling is an efficient plan because of the high level of accuracy demanded and the small number of scheduled trips. The theory of two-stage sampling is reviewed, and modifications are derived for times when the second-stage sample size varies between primary units. Sampling plans for light rail lines in greater Los Angeles and San Jose are offered as examples. Necessary samples sizes are as low as 25 round trips for 10 percent annual precision at the 95 percent confidence level, 80 round trips for 5 percent precision, and 400 round trips for 2 percent precision.

Responsible management demands reliable ridership estimates in order to monitor system performance, to track and forecast ridership and revenue trends, and to fulfill FTA Section 15 reporting requirements. However, estimating transit ridership poses a challenge for nearly every North American system because in most systems all passengers are not routinely counted. Ridership estimation is done by sampling, for which many techniques have been advanced. This paper describes a statistically based sampling technique that is appropriate to barrier-free light rail lines (although it certainly can be used in other situations as well) and its application to two new West Coast systems.

Statistical sampling is an established discipline, covered, for example, in the work by Cochran (*1*). Stopher and Meyburg's text reviews sampling in the context of transportation planning (*2*). Application of statistical sampling techniques to transit began with the *Bus Transit Monitoring Manual* (BTMM) (*3*) and its update, the *Transit Data Collection Design Manual* (TDCDM) (*4*), both of which were written for bus systems. In part, these manuals were driven by UMTA Section 15 requirements that systems receiving operating assistance report, among other things, systemwide annual estimates by mode of boardings and passenger miles that are based on a statistically sound methodology and satisfy specific accuracy requirements (10 percent precision at the 95 percent confidence level). UMTA published circulars describing two approved methodologies for bus systems (*5,6*) and one for demand-responsive systems (*7*), but no standardized method for light rail or other modes has been established. Applications of statistical methodologies seeking greater efficiency than the standard techniques have been published, but again they are designed for bus systems. These applications include cluster sampling (*8*), ratio-based estimation (*9*), and regression-based estimates (*10*).

Ridership sampling for barrier-free light rail systems demands special attention for several reasons. First, accurate ridership estimates are sought for a single line or a very small number of lines; for bus systems, however, total ridership must be estimated over a large number of lines. Light rail systems can therefore be expected to exhibit less variability than bus systems, and techniques that reduce between-line variability such as stratifying by line type or line length become moot. Second, greater accuracy is often sought for light rail lines, particularly new lines whose ridership levels are being watched carefully by public officials and the press. The intensive sampling needed to achieve high levels of accuracy, when applied to a single light rail line, means that there is a high likelihood that a particular scheduled trip will be sampled more than once, and it is even possible that every scheduled trip will be sampled once or more. Statistical techniques that assume an infinite population of scheduled trips can safely be used for a bus system in which a few trips are sampled each week from a sampling frame of thousands of daily trips, but not for a light rail system in which a large fraction of the scheduled trips is sampled each month.

Third, barrier-free systems with off-vehicle revenue collection do not easily lend themselves to revenue-based sampling, a very efficient technique in many bus systems. Revenue-based estimation typically requires jointly measuring ridership and revenue for a sample of trips, and when there is no on-board revenue collection it is virtually impossible to assign revenue to a specific trip. Revenue-based estimation can be done on a basis other than vehicle trips, for example, by correlating boardings during a sample of time intervals at a sample of stations to revenue collected at ticket-vending machines at those stations during those intervals; but this approach raises a host of issues of its own. For example, it provides no measurement of passenger miles; in addition, there can be a huge variance in revenue per passenger at different stations and different times of day due to transfer patterns, availability of round-trip tickets, and pass use patterns.

Finally, the greater accuracy demands of new light rail systems and their larger vehicles make load-based estimation, a technique used in several bus systems, impractical. One unpublished study of the accuracy of wayside bus load measurements suggests a mean absolute error of 13 percent and a bias of 3 to 6 percent. A load-based estimate has three sources of error. The first two are sampling errors, first in the load data and second in ride check data (load, boardings, and passenger miles data used to derive the ratio-to-load fac-

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tors). These errors can be reduced by making more point checks and more ride checks. However, the third source of error, bias in the load measurements, cannot be diminished by increasing sample size, making high accuracy unattainable using wayside counts. Even if measurement error were eliminated (e.g., by having checkers count on board the vehicle, introducing a new set of problems), the compounded errors from the point check sample and the ride check sample limit the value of the technique to desired precision levels of 10 percent or greater.

ESTIMATION METHODS IN USE

An informal survey of light rail operators was conducted, supplementing an earlier survey performed by Kumar and Parry (*11*), to see what techniques are used to estimate ridership on light rail lines in the U.S. and Canada. Three relatively new barrier-free systems use a technique described later in this paper, a special case of two-stage sampling in which every scheduled trip is sampled several days a year. In another barrier-free system, ticketed boardings are counted directly from ticket-vending machines, and nonticketed (i.e., pass, transfer, and free) boardings are estimated from a random sample of trips expanded in proportion to ticketed boardings. A fifth barrier-free system expands a random sample of trip portions by service minute rather than simply by number of trips. Among other light rail systems, a variety of methods are used, including the methods of Circular 2710.1 (*5*) (direct expansion of a sample of about 550 trips), Circular 2710.4 (*6*) (revenue-based expansion of a sample of 208 trips), and others (*4*) (expansion of point load data based on ratio-to-load factors that are updated every few years). At least one system uses a sampling method for Section 15 reporting while using electronic farebox and turnstile counts without sampling for internal purposes. Another uses revenue-based expansion in which the ratio-to-revenue factors are updated every few years and there is no sampling during the intervening years. The Canadian systems, which are not subject to Section 15 requirements, do not sample for passenger miles and are less systematic in estimating boardings than the U.S. systems, preferring to concentrate on peak load.

TWO-STAGE SAMPLING METHODOLOGY DEVELOPED FOR SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT METRO BLUE LINE

The Metro Blue Line is a 23-mi-long light rail facility connecting downtown Los Angeles to downtown Long Beach. This 22-station line, operated by the Southern California Rapid Transit District (SCRTD), was opened to the public on July 14, 1990. Like recently completed light rail facilities in San Diego, Sacramento, San Jose, and Portland, the fare collection systems on the Metro Blue Line are barrier-free, meaning that patrons are required to neither go through any turnstiles or fare gates nor show their fare media to an on-board operator or conductor. Under a contract from SCRTD, fare payment is enforced by a team of roving county deputy sheriffs who, besides patrolling the line for security purposes, are authorized to randomly inspect passengers for valid fare media.

Being the first new rail project in the Los Angeles area in more than 30 years and the first segment of a 150-mi rail rapid transit system currently under development, the Metro Blue Line drew considerable attention from the local news media and elected officials at the time of its opening.

For about 2 months, ridership was tracked on a daily basis and shared with the news media. The passenger counting program is conducted by unionized schedule checkers employed by SCRTD. As operations stabilized, attention was focused on finding an efficient, statistically sound methodology for making reliable quarterly and annual patronage estimates for both internal management and external reporting purposes.

Several considerations dictated the statistical methodology chosen for estimating ridership. First, because there was no auxiliary variable such as revenue suitable for ratio estimation, boardings would be estimated and expanded directly. Second, both sampling efficiency and variance reduction suggest using the round trip as the sampling unit rather than the one-way vehicle trip. Third, variance reduction and economy suggest estimating weekday, Saturday, and Sunday ridership in separate strata. Finally, the population of transit trips has a natural two-dimensional structure—that is, the fundamental sampling element is trip (i,j), the ith scheduled trip on the jth day. Because there is one pattern of variation between scheduled trips and another pattern of variation between days, the appropriate technique is two-stage sampling.

Review of Two-Stage Sampling

Two-stage sampling means sampling a number of primary units, and then, for each selected primary unit, sampling a number of elements or subunits within that primary unit. An example of two-stage sampling is the methodology of UMTA Circular 2710.1 (*5*), in which a number of days (the primary unit) is selected, and for each selected day a number of trips is selected. Because for a given day type each trip is run every day, we have two-stage sampling with primary units of equal size. The discussion will assume simple random sampling at each stage unless noted otherwise. Notation and definitions, following Cochran's text (*1*), are as follows:

N = number of primary (Stage 1) units in population

M = number of subunits (Stage 2) in population of each primary unit

$\overline{Y}_i$ = population mean per subunit in primary unit i

$\overline{\overline{Y}} = $ population mean per subunit overall $= \frac{1}{N} \sum \overline{Y}_i$

n = number of primary units sampled

m = number of subunits sampled in each primary unit

y_{ij} = value for jth subunit in ith primary unit

$\overline{y}_i = \frac{1}{m} \sum_j y_{ij}$ = sample mean per subunit in ith primary unit

$\overline{\overline{y}} = \frac{1}{n} \sum \overline{y}_i$ = overall sample mean per subunit

$S_1^2 = \frac{1}{N-1} \sum (\overline{Y}_i - \overline{\overline{Y}})^2$ = variance among primary unit means

$S_2^2 = \frac{1}{N(M-1)} \sum_i \sum_j (y_{ij} - \overline{Y}_i)^2$ = variance among subunits within primary units

As Cochran demonstrates, $\overline{\overline{y}}$ is an unbiased estimate of $\overline{\overline{Y}}$, and its variance, accounting for the finite population correction, is

$$V(\overline{\overline{y}}) = \left(\frac{N-n}{N}\right)\frac{S_1^2}{n} + \left(\frac{M-m}{M}\right)\frac{S_2^2}{mn}$$
$$= \frac{1-f_1}{n}S_1^2 + \frac{1-f_2}{mn}S_2^2 \quad (1)$$

where $f_1 = n/N$ and $f_2 = m/M$ are the sampling fractions in the first and second stages, and $(1 - f_1)$ and $(1 - f_2)$ are the finite population corrections.

Of course, S_1^2 and S_2^2 are unknown and must be estimated from data. Define the sample Stage 1 variance and the sample Stage 2 variance as

$$s_1^2 = \frac{1}{n-1} \sum (\overline{y}_i - \overline{\overline{y}})^2 \quad (2)$$

$$s_2^2 = \frac{1}{n(m-1)} \sum_i \sum_j (y_{ij} - \overline{y}_i)^2 \quad (3)$$

As Cochran points out, s_2^2 is an unbiased estimator of S_2^2. However, s_1^2 overestimates S_1^2 because s_1^2 is calculated from sample means rather than true means, introducing additional variance that is proportional to the variance of these sample means. Correcting for this additional variance yields the following unbiased estimate of S_1^2:

$$s_1^2 - \frac{s_2^2(1 - f_2)}{m} \quad (4)$$

Two-Stage Sampling Schemes for Transit

As mentioned earlier, UMTA Circular 2710.1, as well as the BTMM, use two-stage sampling for transit ridership in which the day is the primary stage and the trip is the subunit. (Their sampling plans involve a degree of systematic sampling in the selection of days, for the same number of days is selected each week. This departure from simple random sampling is expected to have a small but beneficial effect on precision and a negligible effect on bias, and can therefore be ignored.) The other possible two-stage scheme is to have the trip be the primary unit. In this scheme a number of trips would be selected from the daily schedule, and each trip would then be sampled on a fixed number of randomly selected days.

The more efficient scheme is simply the one with the lowest total sample size (i.e., total trip-day combinations), since neither scheme offers any significant efficiencies in collecting the data. (In addition, the first scheme can concentrate the checking on a smaller number of days, which may have a small impact on manpower availability.) Under either scheme, it will usually be efficient to define "trip" as a round trip, since checkers must usually make round trips anyway in order to return to their starting point. Efficiency therefore depends on the Stage 1 and 2 variances and the finite population corrections, as indicated by Equation 1.

For estimating ridership of a bus system composed of many bus lines, the first scheme appears appropriate. There are only 250 or so weekdays per year as opposed to thousands of trips in the daily schedule, so if the day is the primary unit it is certainly plausible that the finite population correction for Stage 1 will be considerably below unity, or even zero if every day is sampled, substantially reducing or eliminating the Stage 1 variance's contribution to standard error and leaving as the main source of variability the variance between trips on a given day, which, while large, is divided in Equation 1 by mn, the total number of subunits in the sample. However, for a simple light rail line the second scheme, with the trip as the primary unit, appears more natural. The weekday schedule is likely to have about 100 round trips, fewer than the number of weekdays in a year, so the Stage 1 finite population correction factor can more easily become zero under Scheme 2. If the sample size is at least 250, Stage 1 variance vanishes for either scheme, and efficiency depends entirely on second-stage variance, which in Scheme 1 depends primarily on peaking of demand and in Scheme 2 depends on day-to-day variation in demand and operations. In Figure 1, second-stage variability is illustrated for both schemes on the basis of Metro Blue Line data. It was expected—and the data in Figure 1 confirm the expectation—that the second-stage variance would be smaller under Scheme 2. As it turned out, the difference between the two schemes was not as great as expected.

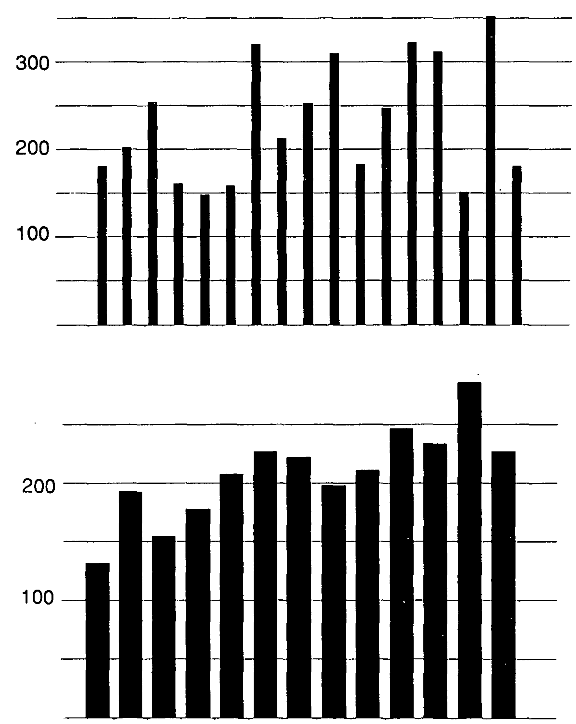

FIGURE 1 Second-stage variability for two sampling schemes: *top*, Scheme 1, within a day; *bottom*, Scheme 2, within a trip.

Varying Second-Stage Sample Sizes

The available Metro Blue Line data had been sampled following the first scheme—that is, days were selected at random each week and trips were selected at random for each selected day. Matters were complicated by the fact that the sampling rate had changed overtime—sampling had been more intensive soon after the line opened because both management and public interest were great at that time. Therefore, although each primary unit (the day) is still equal in size (same number of trips), the second-stage sample size was not the same across all sampled days. Letting

m_i = number of subunits sampled within primary unit i

the sample within unit variance should be defined as follows:

$$s_2^2 = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{\sum_{j=1}^{mi}(y_{ij} - \bar{y}_i)^2}{m_i - 1}\right] \tag{3a}$$

$$s_2^2 = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{\sum_{j=1}^{mi}(y_{ij} - \bar{y}_i)^2}{m_i - 1}\right] = \frac{1}{n}\sum_{i=1}^{n} s_{2i}^2 \tag{3b}$$

which is then an unbiased estimator of S_2^2. An unbiased estimator of S_1^2 is then

$$s_1^2 - \frac{s_2^2(1 - f_2')}{\overline{m}'} \tag{4a}$$

where $\overline{m}'$ is the harmonic mean of the second-stage sample size given by

$$\overline{m}' = \frac{1}{\frac{1}{n}\sum\frac{1}{m_i}} \tag{5}$$

and

$$f_2' = \frac{\overline{m}'}{M} \tag{6}$$

Furthermore, the variance of the final estimate, given in Equation 1, should be modified by replacing m with $\overline{m}'$ and f_2 with f_2'.

To find the expected value of an estimate, first average over all possible second-stage samples for a fixed set of n Stage 1 units. Then average this result over all possible Stage 1 samples of n units. This logic can be represented as $E(\bullet) = E_1[E_2(\bullet)]$. Applying this logic to Equation 3a,

$$E_2\left[\frac{\sum_{i=1}^{mi}(y_{ij} - \bar{y}_i)^2}{m_i - 1}\right] = S_{2i}^2 \tag{7}$$

where S_{2i}^2 is the variance among subunits within the ith primary unit. Therefore

$$E_2(s_2^2) = \frac{1}{n}\sum S_{2i}^2 \tag{8}$$

Then averaging over all possible first stage samples of size n,

$$E(s_2^2) = E_1[E_2(s_2^2)] = S_2^2 \tag{9}$$

To obtain the expected value of s_1^2 (still given by Equation 2), two results should first be established. First, given that unit i has been selected in Stage 1 and asigned to have m_i randomly selected subunits sampled, the variance of the Stage 2 sample mean of unit i is, from the theory of simple random sampling without replacement,

$$\text{var}_2(\bar{y}_i) = S_{2i}^2\left(\frac{M - m_i}{Mm_i}\right) \tag{10}$$

Likewise, for a given Stage 1 selection and a given assignment of Stage 2 sample sizes m_i,

$$\text{var}_2(\bar{\bar{y}}) = \text{var}_2\left(\frac{1}{n}\sum \bar{y}_i\right) = \frac{1}{n^2}\sum S_{2i}^2\left(\frac{M - m_i}{Mm_i}\right) \tag{11}$$

Considering now s_1^2, we know that

$$\sum(\bar{y}_i - \bar{\bar{y}})^2 = \sum \bar{y}_i^2 - n\bar{\bar{y}}^2 \tag{12}$$

so that

$$\begin{aligned}(n-1)E_2(s_1^2) &= E_2\left(\sum \bar{y}_i^2\right) - nE_2(\bar{\bar{y}}^2)\\ &= \sum \bar{Y}_i^2 + \sum S_{2i}^2\left(\frac{M - m_i}{Mm_i}\right)\\ &\quad - n\bar{\bar{Y}}_n^2 - \frac{1}{n}\sum S_{2i}^2\left(\frac{M - m_i}{Mm_i}\right)\\ &= \sum\left(\bar{Y}_i - \bar{\bar{Y}}_n\right)^2\\ &\quad + \left(\frac{n-1}{n}\right)\sum S_{2i}^2\left(\frac{1}{m_i} - \frac{1}{M}\right)\end{aligned} \tag{13}$$

where $\bar{Y}_n$ is the population mean per subunit for the selected n primary units.

When averaging over all possible Stage 1 samples of n units with assigned Stage 2 sample sizes m_i, random sampling and random assignment implies that

$$E_1\left[S_{2i}^2\left(\frac{1}{m_i}\right)\right] = E_1(S_{2i}^2)E_1\left(\frac{1}{m_i}\right) = S_2^2\frac{1}{\overline{m}'} \tag{14}$$

Therefore, dividing Equation 13 by $(n - 1)$ and taking the expectation over Stage 1,

$$\begin{aligned}E(s_1^2) &= S_1^2 + S_2^2\left(\frac{1}{\overline{m}'} - \frac{1}{M}\right)\\ &= S_1^2 + \frac{S_2^2}{\overline{m}'}(1 - f_2')\end{aligned} \tag{15}$$

from which Equation 4a follows. The proof for the modification to Equation 1 follows the same line of reasoning.

Metro Blue Line Results

Results for Scheme 1 are presented in Table 1, Column a on the basis of weekday data from July 1991 through February 1992, during which time the rail line schedule and the sampling schedule were relatively stable. Variance information is presented in the form of coefficient of variation (relative standard deviation) or *cv* = (square root of variance)/mean, since the *cv* is more readily visualized and is closely related to statistical precision. As indicated in the table, the Stage 1 sample *cv* (variation between the sample means of the sampled days) is 21 percent, on the basis of a sample of 135 days with a harmonic mean = 1.3 trips per day. The Stage 2 sample *cv* (variation between trips within a day) is 22 percent, on the basis of data from 56 days on which multiple trips were sampled (harmonic mean of 2.3 trips per day). This figure conforms with expectations based on occasional 100 percent ride checks (checking every trip on a given day). The estimated Stage 2 *cv* is the same as the sample Stage 2 *cv*, 22 percent, but the estimated Stage 1 *cv*, 9 percent, is far smaller than the sample Stage 1 *cv*. This is a good example of the bias inherent in the sample Stage 1 variance—it incorporates variance from both the true Stage 1 variance and from the sampling variance inherent in a sample of only (on average) 1.3 trips per day. Applying Equation 4a with *cv*'s and ignoring the insignificant Stage 2 finite population correction,

$$cv_1^2 = CV_1^2 + CV_2^2/\bar{m}' \cong CV_1^2 + cv_2^2/\bar{m}'$$

$$0.21^2 = 0.09^2 + 0.22^2/1.3$$

where CV_i is population stage *i* coefficient of variation and cv_i is sample stage *i* coefficient of variation.

With these results, first- and second-stage sample sizes necessary to achieve a given precision level can be determined by trial and error. For the Metro Blue Line, and probably for most light rail lines, efficient plans for increasing levels of precision involve sampling one trip per day for *n* days until every day is covered once, then adding a second trip, and so on. (Under such a plan, the Stage 2 finite population correction can be neglected.) The sample size necessary to estimate annual weekday boardings to a precision of 10 percent was found to be one round trip per day for 22 days, which compares favorably with the more than 540 randomly selected one-way trips required by UMTA Circular 2710.1. For 5 percent precision, the necessary sample size is 1 round trip per day for 82 days, and for 2 percent precision it is 2 round trips per day, every weekday of the year, for a total sample size

TABLE 1 Sampling for Weekday Boardings

	(a)	(b)	(c)	(d)
sampling element	round trip	round trip	round trip	one-way trip
stage 1	date	trip	trip	trip
stage 2	trip	date	date	date
N	255	112	224	206
M	112	255	128	255
ANALYSIS DATASET				
n	135	112	same	206
m	1.3	1.3	as	2.3
total sampled trips	219	219	(b)	757
mean	395	385		46.5
cv	0.21	0.26		0.58
cv	0.22	0.19		0.32
Estimated CV	0.09	0.19	0.19	0.54
Estimated CV	0.22	0.19	0.19	0.32
SAMPLING PLAN FOR 10% PRECISION (m=1)				
n	22	26	27	98
SAMPLING PLAN FOR 5% PRECISION (m=1)				
n	82	76	91	190
SAMPLING PLAN FOR 2% PRECISION				
n	255	112	224	206
m	2	3.25	1.75	5
m	2	3.2	1.6	5
nm = sample size	510	364	392	1030

(a) Metro Blue Line, scheme 1
(b) Metro Blue Line, scheme 2
(c) Metro Blue Line, scheme 2 with thorough midyear timetable change
(d) Guadalupe Line, scheme 2

of 510 round trips. (Here and throughout the paper the 95 percent confidence level is used, for which the precision is 1.96 times the relative standard error.)

The same data set was used to test the second scheme for two-stage sampling, namely, selecting *n* trips at the first stage and then selecting *m* days on which to sample each selected trip. The results of this analysis are approximate since they are based on a sample that was selected after the first scheme, so that the selection of days is not entirely independent from one trip to another. The results, presented in Table 1, Column b, are that the Stage 1 (variation between the means of different round trips) *cv* is estimated to be 19 percent, and the Stage 2 (variation between days for a given round trip) *cv* is also estimated to be 19 percent. Consequently, the sample sizes needed to achieve 10, 5, and 2 percent precision, respectively, are 26, 76, and 364 round trips. The latter case involves sampling every trip 3.25 times on average, meaning 75 percent of the round trips are sampled three times a year and the rest are sampled four times. The harmonic mean of the second-stage sample size is 3.2, so whereas the sampling cost is proportional to 3.25 days per trip, the precision is calculated as if there were only 3.2 days per trip.

Comparing the two schemes, there appears to be little difference except when the sample size is large enough that nearly every Stage 1 unit is covered, in which case the effect of the Stage 1 variance is greatly diminished by the finite population correction and the critical factor is the Stage 2 variance. The prior expectation was that the Stage 2 variance in Scheme 2 (variation between days for a given trip) would be considerably smaller than the Stage 2 variance in Scheme 1 (variation between trips for a given day), making Scheme 2 more efficient. However, the available data show only a small advantage for Scheme 2. Given the limited scope and imperfections of the data set, further data collection and analysis will be needed before anything definitive can be concluded about the relative efficiencies of the two schemes. Further data collection and analysis will also be needed to see that the levels of variance observed are maintained as the systems matures.

Practical Considerations

Transforming these results into actual sampling plans for the Metro Blue Line required some modifications to account for several complications.

1. Data were available for 2 fiscal years, 1990–1991 and 1991–1992. Both data sets were analyzed and *cv*'s were taken as an average for the 2 years, with a greater weight placed on the more recent year.

2. The same analysis was applied to Saturday and Sunday data. In the final sampling plan each day type is a separate stratum. For the final annual estimate the strata are combined using standard formulas for stratified sampling.

3. The trip schedule does not consist only of simple round trips. There are pull-outs and pull-ins as well from the depot that is located along the line about 3 mi from the Long Beach terminal. Therefore, the sampling unit is a generalized round trip, which may be a simple round trip, a round trip plus a pull-in or pull-out between the depot and Long Beach, or a depot–Los Angeles–Long Beach trip, or any other combination whose ridership is expected to be comparable to that of a simple round trip. The daily schedule should be divided a priori into sampling units, and each sampling unit selected with equal probability (within a day type stratum).

4. What if the timetable changes during the year? For Scheme 1, this change could be ignored, assuming the underlying between-day and between-trip variations do not change much. For Scheme 2, a thorough timetable change can be treated like a doubling of the number of scheduled trips and a halving of the number of days each trip runs. This modification can affect significantly the magnitude of the finite population correction (since the population of trips doubles), reducing the efficiency of the method. If the timetable change is partial (as are most timetable changes), the effect is less severe. A sampling plan for the Metro Blue Line that assumes there will be one thorough timetable change in the year is shown in Table 1, Column c. Sample sizes are only a little higher than with no timetable change, assuming no change in the Stage 1 and 2 variances. Of course, if the timetable change significantly affects the underlying variances (e.g., changing departure times to smooth out vehicle loads should reduce the between-trip variance), the underlying variances should be reestimated, and the before and after parts of the year treated as separate strata.

5. As mentioned earlier, with either scheme the most efficient sampling plan for moderate to high levels of precision calls for only one second-stage sample per primary unit sample. The data generated by this kind of sampling are insufficient to reestimate S_1^2 and S_2^2 in the future. Therefore, it is recommended that a sampling plan involving 2 days per trip be followed every third year or so to permit reestimation of the underlying variances. To illustrate the loss of efficiency from increasing the Stage 2 sample size, an analysis was done for Scheme 2, considering a stratified sample with three day types, a mid-year schedule change, and a given number (124) of round trips. Sampling 62 round trips on 2 days each resulted in a precision of 7.2 percent, and sampling 124 round trips on 1 day each yielded a precision of 5.5 percent.

SAMPLING METHODOLOGY FOR SANTA CLARA COUNTY TRANSIT DISTRICT GUADALUPE LINE

The Guadalupe Light Rail Line is operated by the Santa Clara County Transit District in a north-south corridor through downtown San Jose, California. Like the SCRTD Metro Blue Line, the Guadalupe Line is barrier-free, with ticket-vending machines and multiticket canceling machines on station platforms. The ride check data available for this study came from 1990, when only the downtown and northern portions of the line were open.

Like the Metro Blue Line, the Guadalupe Light Rail line is the first light rail line in its county in several decades. Its ridership is changing rapidly as people accommodate their travel patterns to the line's availability and as new segments of the line open. Both management and the general public have a keen interest in tracking ridership. Therefore, ridership estimates must be more accurate than the annual 10 percent precision mandated by Section 15. After consulting with management, it was concluded that the desired precision was 1 to 2 percent for annual estimates, corresponding to a precision of 2 to 4 percent for quarterly estimates. At this level it was clear that data collection would have to be sufficiently intensive to cover every trip in the schedule once a month for weekday trips and once a quarter for Saturday and Sunday trips. The sampling method then is a special case of two-stage sampling following Scheme 2 (first select trips, then select days for each trip) in which every trip in the schedule is selected; in effect, it becomes stratified sampling with each trip representing a stratum. Because every Stage 1 unit is sampled, Stage 1 variance is inconsequential; the only contribution to the variance of the estimate comes from Stage 2 variance, the variance between days for a given trip.

Presented in Table 1, Column d are the results from analysis of Guadalupe Line weekday data. The Stage 2 *cv* is 32 percent. This value is considerably higher than the corresponding variance for the Metro Blue Line (22 percent). Recognizing that mean boardings were about 50 per one-way trip on the Guadalupe Line and about 400 per round trip on the Blue Line, this result is in keeping with the common finding that the *cv* diminishes as the ridership level increases and suggests that the variance on the Guadalupe Line will diminish as the line expands and ridership grows. The Saturday and Sunday Stage 2 *cv*'s are still greater: 64 and 45 percent, respectively. Estimating weekday ridership with a 2 percent annual precision requires sampling all 206 weekday trips five times a year, for a total of 1,030 one-way trips. For 5 and 10 percent precision estimates, the high between-trip *cv* necessitates sampling 190 and 98 one-way trips, respectively, once a year.

Alternative sampling plans were recommended for the time after the southern portion of the line opened. By way of illustration, one plan was to sample each weekday trip once every 2 months and each weekend trip once a quarter. Assuming that the *cv*'s will be the same after the line expands, an assumption that the authors consider conservative, this plan is expected to achieve 1.5 percent precision in the estimate of total annual boardings and 3 percent precision for quarterly estimates. Calculations for this stratified sampling plan are shown in Table 2. The following formulas are used in that table (the Stage 2 finite population correction is ignored):

h = stratum identifier

w_h = stratum weight = (total trips)$_h$/(total trips)

$$\text{variance} = \sum_h [w_h(\text{mean per trip})_h(\text{within trip } cv)_h]^2/n_h m_h$$

$$\text{mean} = \sum_h w_h(\text{mean per trip})_h$$

$$\text{precision} = 1.96\sqrt{\text{variance}}/\text{mean}$$

It is interesting to note that if each sampling unit (a date-trip combination) is treated as an independent unit without recognizing its two-stage structure, the sample size necessary to achieve a given level of precision would be a little more than three times larger than needed when the two-stage structure is exploited. If the sampling units are stratified into 10 strata by period (Saturday, Sunday, and four weekday periods) and by direction (for weekday only), the necessary sample size would still be almost twice as large as required by the two-stage scheme, which is effectively stratified sampling with about 500 strata (one each for 231 weekday, 135 Saturday, and 135 Sunday trips).

RELATIONSHIP TO OTHER PUBLISHED SAMPLING PLANS

It seems appropriate to contrast the methodology described in this paper with those in the four major publications dealing with statistical sampling for transit ridership: the BTMM (*3*); its update, the TDCDM (*4*); and UMTA Circulars 2710.1 (*5*) and 2710.4 (*6*), all of which were written primarily for bus systems.

The BTMM assumes a two-stage sampling plan. Circular 2710.1 is based on its methodology and established necessary sample sizes by using default values for the Stage 1 and 2 variances and ignoring the finite population correction. The BTMM formulas differ from those used in this paper in two

TABLE 2 Stratified Sampling Plan for Guadalupe Line

	Wkday	Sat	Sun	Total
N (trips)	231	135	135	
M (days)	255	52	58	365
total trips = MN	58905	7020	7830	73755
stratum weight	0.799	0.095	0.106	
mean per trip	46.5	37.7	35.2	
mean contribution	37.1	3.6	3.7	44.5
within trip cv	0.32	0.64	0.45	
SAMPLING PLAN				
n	231	135	135	
m	6	4	4	
sampled trips = mn	1386	540	540	2466
variance contribution	0.0976	0.0090	0.0049	0.1116
standard error				0.334
precision @ 95% conf.				1.5%

ways, and it seems proper to explain the differences for the sake of avoiding confusion.

1. The BTMM uses s_1^2, the variance between Stage 1 sample means, as an estimator of S_1^2, the variance between Stage 1 true means. As we have shown, s_1^2 is always greater than S_1^2 because the former incorporates a degree of Stage 2 sampling variation inherent in the sample means. Omitting the correction from the BTMM makes its results more conservative than necessary.

2. The BTMM formula for Stage 1 or between-day variance (*3*,p.118) differs from Equation 2 in that each primary unit is weighted by the number of subunits sampled, k_i (called m_i in this paper). The BTMM formula for Stage 2 or within-day variance (3,p.119) differs from Equation 3a likewise. Weighting is appropriate only in the case of a stratified sample (e.g., a sample that includes weekday and weekend trips). However, even in such a case the weights should be the population weights, not the sample weights. Therefore, these formulas are valid only when the sample weights are the same as the population weights (e.g., when every trip, regardless of stratum, has an equal probability of selection). The examples presented in the BTMM (*3*,pp.134–135) have equal sampling rates, and are therefore correct. However, if the sampling rate is not the same in all strata, or if some weekdays are sampled more often than others (say, due to invalid samples being discarded), the BTMM formula will bias the results in favor of the days that, for whatever reasons, are overrepresented in the sample.

Circular 2710.4 and the TDCDM model the sampling process as simpler one-stage sampling, assuming that trip-day combinations are simply selected at random. (In fact, as in Circular 2710.1, selections in Circular 2710.4 are not purely random but contain a systematic element in that an equal number of selections are made for every week.) These documents retreat from the two-stage sampling of their antecedents because when there are thousands of trips in the daily schedule, as is the case in large bus systems, and the required precision demands a sample of fewer than one trip a day, the possibility of a trip being repeated in a one-stage sample is so remote that a one-stage sample is essentially indistinguishable from a two-stage sample. It can easily be shown that (a) when $m = 1$ (i.e., each sampled trip is sampled only once) and (b) the finite population corrections at both stages are negligible, the two-stage estimates of the overall mean per trip and of its variance become identical to single stage estimates from an infinite population, which is the assumption of the TDCDM and Circular 2710.4. Why then does this paper revert to two-stage sampling? Because the vastly smaller number of scheduled trips and the greater demands for accuracy on a light rail line make it almost certain that a one-stage sample will include some scheduled trips many times while other trips are excluded, whereas a two-stage sample can be designed to provide for even coverage of all trips. Even coverage is more efficient statistically and benefits the transit agency more in meeting other data needs.

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Strategic Transit Work Force Planning Model Incorporating Overtime, Absence, and Reliability Relationships

YORAM SHIFTAN AND NIGEL WILSON

The optimal size of a transit operating work force is based on the appropriate amount of overtime that can be requested of the work force. Overtime is typically used to fill in for absent operators if no extra operators are available to do the work on regular time. However, relying more heavily on overtime has two risks. First, no operator may be willing and available to work overtime when it is needed. This will result in missed service and hence poor service quality. Second, operators may be absent more often because they can readily obtain overtime work at a significant wage premium. These interrelationships between overtime, absence, and service reliability are examined, and ways in which they influence the overall work force planning problem are shown. It was found that absence is more a habit than a result of a decision process based on past overtime worked. Strong linear relationship was found between absence and overtime. This result makes it possible to include reliability constraints in the strategic work force planning process by setting an upper limit on the amount of overtime that can be planned for a given period. In addition, a two-stage heuristic is developed for solving the strategic work force planning problem. This heuristic is used in a case study of the Massachusetts Bay Transportation Authority bus system to show the importance of various policies with respect to work force planning and management.

Transit work force planning deals with the problem of determining the most cost-effective staffing level for transit operators, those employees directly responsible for operating transit vehicles. Given the importance of service reliability and the uncertainty about both the manpower that will be available and the amount of work to be performed on a given day, transit agencies employ more operators than those actually scheduled for work. These extra operators are usually referred to as the extraboard (also known as the spare board or cover list). Too large of an extraboard will result in low productivity because some operators who do not have any useful work to perform must still be paid. On the other hand, too small of an extraboard implies that a large amount of overtime, at high marginal cost, must be requested from regular operators and furthermore that service reliability will be jeopardized.

In the past decade considerable attention has been focused on ways to improve productivity in the transit industry. Traditionally, strategic work force planning decisions have been made by relying on experience directly or by using rules of thumb that are themselves based on operating experience. Because of the complexity of the problem there have been few attempts to approach this problem analytically until recently, when MacDorman initiated work leading to the TOPDOG software for work force planning (*1–3*).

Over the past 6 years researchers at the Massachusetts Institute of Technology have also made considerable progress in solving this problem by working closely with managers and staff at the Massachusetts Bay Transportation Authority (MBTA). The work has shown that this problem can indeed be approached analytically and that the resulting models can provide a powerful tool for planning and managing a transit work force.

This paper is aimed at better understanding the potential for improved work force management throughout the industry to increase productivity and lower costs. Special attention is given to incorporating labor supply issues in the model, in particular those that relate absence and overtime. In addition, the relationship between overtime and system reliability is investigated. Including these relationships in this type of model makes it more realistic and thus more attractive for implementation.

WORK FORCE PLANNING RELATIONSHIPS

Figure 1 shows these interrelationships among work force planning, requested overtime, employee absence, and service reliability. Overtime may come in two forms: that which is included in the scheduled run, and that which is beyond the run. Requested overtime refers only to the latter form of overtime. In Figure 1 the labor supply issues associated with absence and overtime are indicated by curved boxes. The upper part of the figure shows the classic work force planning problem as described by Koutsopoulos and Wilson (*4*) and by Hickman et al. (*5*).

An important output of the strategic model is the amount of open work (equivalent to the amount of requested overtime) in the system. Open work is the difference between required extra work and extra manpower available. Employee absence, which is a major component of required extra work, depends on the willingness and ability of individual employees to work whereas the manpower available for extra work consists of the extraboard, one of the decision variables in the

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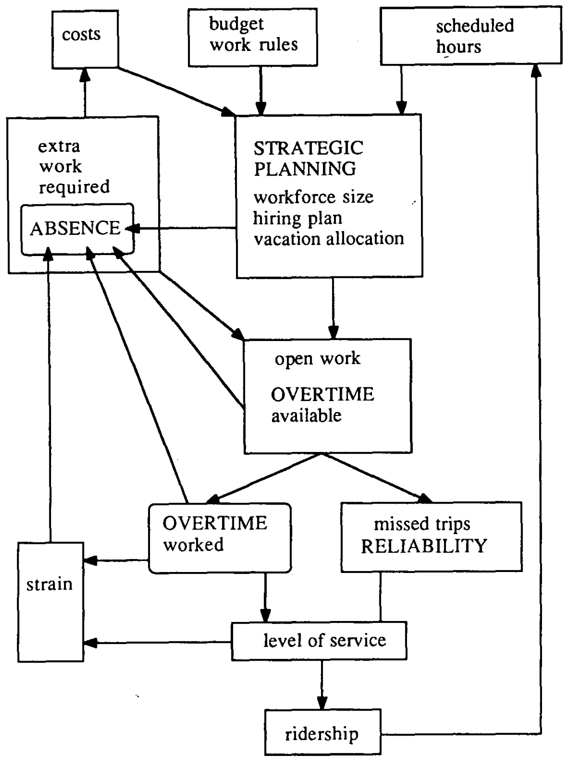

FIGURE 1 Strategic work force planning, absence, overtime, and reliability relationships.

model. However, management decisions on overtime may affect employee absence rates as well as employee willingness to work overtime.

As an illustration, consider the following situation. If the total cost per hour of labor is lower for an overtime employee than for a regular employee, the naive solution would be to rely heavily on overtime. This situation is common in the transit industry because the high cost of fringe benefits can outweigh the 50 percent pay differential for overtime work. The naive solution would be most inappropriate for two reasons. First, at most agencies, employees have the right to decline overtime work if they so choose, and greater reliance on overtime produces more situations in which no employee can work overtime. Whenever this occurs, scheduled service will not be operated, affecting service reliability. Service reliability is an important determinant of passenger satisfaction, and hence can be expected to affect demand as well as political and public support for the system.

Second, if large amounts of overtime are used, levels of employee absence may well increase for two reasons. Some employees may be more likely to be absent after reaching a threshold pay amount for a week, and this level can be reached after fewer hours on the job if overtime is readily available. Other operators may be absent more because of the increased stress and fatigue associated with regularly working longer hours. This may lead to increased risk of accidents as well as reduced service quality as a result of operators' being assigned to unfamiliar routes and irregular hours.

At an aggregate level absence affects overtime availability directly by producing open work; at the disaggregate level overtime availability may affect an individual employee's decision to be absent, which in turn will affect total open work. In this paper the disaggregate relationship between overtime and absence is studied. Prior models (*5*) assumed that absence rates (with known mean and variance) were not a function of the decision variables in the model. If absence is a function of overtime, and overtime is a decision variable of the model, it must be recognized at the strategic level.

ABSENCE-OVERTIME RELATIONSHIP

Employee absence is a significant problem within public transport organizations (*1,6*). Perry reported clear links between absence and the liberal availability of overtime work (*7*), and Leahy and Schlegel found that short-term absence was strongly associated with manpower shortages and with operators working on their regular days off (*8*). Perin reported that reducing available overtime was effective in reducing absence (*9*). One piece of evidence to the contrary is from the Twin Cities Metropolitan Transit Commission (*10*), in which increasing the number of operators reduced overtime by about 30 percent without affecting absence.

Theories of Absence

Fishman (*11*) and others have identified the following theories of employee absence:

- Absence is an approach-avoidance behavior. Withdrawal research is based on this premise (*12*), as is most work based on job satisfaction (*13*). Occupational stress may also be included in this category.
- Absence is a result of a decision process. Expectancy models (*14*) and some attitude models (*11*) are based on selecting the action having the most attractive attributes. In the idealized model the employee decides on any day whether or not to work. Economic analysis using utility-maximization or work-leisure trade-off approaches are similar (*15*).
- Absence is a habit. Habit is implicit in the frequent observation that a few workers are responsible for much absence. Predicting absence on the basis of past performance is consistent with, but does not confirm, the habit hypothesis (*16*).

The paper adopts an income-leisure decision model to explore the relationship between overtime and absence.

Income-Leisure Trade-Off

Subjective cost-benefit evaluation by the employee is known as the income-leisure trade-off of work force participation. Under this theory the employee compares the economic and social benefits of work attendance with leisure time and acts accordingly.

Several factors make the leisure-income trade-off more plausible in explaining absence in the transit industry than in some other industries:

- Widespread availability of overtime may allow some employees quickly to recoup wages lost to absence, diminishing the economic benefits of regular work attendance.

- Scheduling inflexibility reduces the operator's ability to take time off when needed for family or other responsibilities, or simply for leisure activities. Some operators may then use sick leave to obtain time off.
- The stochastic nature of open work and the inability to match available operators to open work can result in a cycle in which operators work overtime and then take time off to compensate, resulting in more absence, resulting in more overtime work, and so on.
- The extraboard encourages employee absence because employees are aware that replacements are available. This problem may be perpetuated by the common practice of basing the extraboard size on past levels of employee absence.
- Working long irregular hours causes fatigue, which is a major component of occupational stress that may induce absence. Occupational stress is not included explicitly in the following model, for the practical reason that it is very difficult to measure; however, it is included implicitly since working overtime may increase stress.

MBTA Case Study

Empirical Results

To test the hypothesis that widespread availability of overtime induces absence, a model of absence as a function of overtime and other factors was developed (*6*). For model estimation, data were obtained from the MBTA for a sample of 274 operators from all bus garages for the period July 1989 to September 1990. The data included number of hours each operator was absent each day, the category of each absence, and the weekly payment for overtime worked (the MBTA allows no more than 15 min of scheduled overtime, therefore most overtime is unscheduled). Absences were classified as voluntary, involuntary, or sick because of the different underlying behavioral processes involved. Sick was kept as a separate category because although it is generally genuine and thus involuntary, occasionally it may be a way for an operator to take what is really a voluntary absence.

Table 1 summarizes the absence and overtime variables, including the number of zero values for one (of seven) MBTA garages. In this data set each observation corresponds to an operator weekly record. The occurrence of voluntary absence is very low: less than 10 percent of all absences. To investigate whether sick absence may include some voluntary absences, the durations of sick absences were studied and it was found that 62 percent of sick absences were single days.

In light of the high percentage of 1-day sick absences and in order to model voluntary absences more realistically, new absence variables were defined as short (voluntary plus single-day sick absences) and long (sick absence of at least 2 consecutive days). This assumes that most long sick absences are genuine and most short sick absences are really voluntary. Some short absences are really involuntary and some long absences are voluntary, but there is no more reliable way to distinguish between the two. These categories are also consistent with the payment category: long absences are paid and short ones are not. A model for short absence is consistent with the underlying theoretical model, which assumes that absences are not paid.

A common problem in econometric studies based on labor data is censoring of the dependent variable that occurs when values in a certain range are infeasible. In this application no negative employee absences can exist, a problem which by the large number of zero absence bows observations. The tobit model developed for censored data (*17*), where the underlying distribution is a mixture of discrete and continuous distributions, was used in this study to deal with these problems.

Either frequency or duration may be used as a measure of absence. In this study, duration is used because it is more consistent with the underlying theoretical model: it is the duration of an absence that determines income.

The length of period at which to look for relationships between absence and overtime could be anytime from a day to a year. However, the hypothesized relationships between absence and overtime are not expected to exist at a daily level, since an operator is very unlikely both to be absent and to work overtime in a single day. But information is lost in analysis periods of a month or more. In this study, the basic time unit selected was 1 week: wages in the MBTA are paid weekly so this is the shortest period of perceived income for the operator.

Estimation Results

The absence model (*6*) estimated in this study is the following lagged time-series model:

$$\text{short}_i = \text{short}_i(\text{short\_1}, \text{short\_234}, \text{short\_past}, \text{long\_1}, \text{long\_234}, \text{long\_past}, \text{invol\_1}, \text{invol\_234}, \text{invol\_past}, \text{ot}, \text{ot\_1}, \text{ot\_234}, \text{ot\_past}, \text{winter90}, \text{spring90}, \text{summer90}, \text{oper\_1}, \text{oper\_2}, \ldots, \text{oper\_}n)$$

where

short_i = short absence in week i;
short_1 = short absence in the immediately preceding week;
short_234 = average short absence during preceding weeks 2 through 4;

TABLE 1 Summary of Absence and Overtime Data

	overtime	voluntary absence	involuntary absence	sick	total absence
mean (hr/wk)	0.65	0.12	0.59	1.50	2.20
s. d.* (hr/wk)	1.86	1.90	3.86	5.90	7.27
% obs = 0	79.5	99.3	95.5	89.5	84.9

* *standard deviation*

short_past = average short absence during preceding weeks 5 through 16 [similar definitions hold for the long (long), involuntary (invol) and overtime (ot) variables];

winter90, spring90, and summer90 = seasonal dummy variables; and

oper_i for i = 1, 2, ... n = operator-specific dummy variables.

The model examines whether absence in a particular time period is affected by prior absence of different types as well as by prior overtime worked. The operator-specific dummy variables account for the myriad differences among operators that may influence absence behavior.

Models were estimated separately for a sample of about 40 operators for each garage. The time period in these models is 1 week, although estimating models for different periods of up to 4 weeks led to the same conclusions.

The main conclusions from the estimation results follow:

- Most of the explanatory power in the model is due to the operator-specific dummy variables, for which virtually all coefficients were significant with t-statistics in the range of -1.9 to -5.5. Only 9 out of the 274 operator-specific dummy variable coefficients were not significant.
- None of the lagged overtime variables was significant in explaining current absence, and most tend to be negative, suggesting that those who work overtime tend not to be absent.
- Short_1 always has a positive coefficient that is generally significant, suggesting that operators who were absent in the previous week are more likely to be absent in the current week than those who were not absent in the previous week. This is because some short absences in any week are in fact the continuation of absences in the preceding week. The long_1 variable also has a significant positive coefficient for exactly the same reason: if a long absence in the prior week carries over and ends on the first day of the current week, this latter absence will be classified as a short absence. The other lagged long variables and involuntary lagged absence variables have mixed results, but are mostly insignificant, suggesting that there are no clear relationships between voluntary and involuntary absences including sickness.
- Short_past has negative and significant coefficients. This may be due to the disciplinary policy that limits the total amount of absence that can be taken without having a significant effect on the employee's career in the agency.
- The current-week overtime tends to have a negative coefficient (although only weakly significant) since someone who works overtime can not be absent at the same time, reducing the probability of absence in the same week.
- The winter and spring dummy variables are generally not significant, suggesting that absence in these seasons is not significantly different from absence in the fall. However, the summer dummy variable is positive and significant in three of the seven garages, suggesting that in these garages operators tend to be absent more in the summer.

Interpretation

These estimation results suggest that absence is best interpreted as a habit, that operators differ in their absence rates, and that operators who tend to be absent will always tend to be absent, independent of whether or not they recently worked overtime. If there is any relationship, it would be that those who tend to work overtime also tend to be absent less.

However, studies of absence are very complicated and the data available for this study do not resolve all of the potential problems. For example, even though absences were classified into several categories, it is sometimes difficult to make a clear distinction between voluntary and involuntary absence. Therefore, the lack of a relationship between overtime and absence in our data does not necessarily mean that such a relationship does not exist. There are several other reasons that we may not be able to observe such a relationship even if it does exist. First, we are missing many potentially important variables in the model such as non-labor income and personal and family characteristics, especially financial needs and responsibilities. Second, the level of overtime on the surface system of the MBTA is only about 1.5 percent of scheduled hours, which means that on average each operator works less than 1 hr of overtime per week. Therefore, many operators will not have the option of working any overtime, and it may be that overtime is not available to operators with many absences.

Recall that the two main reasons suggested for absence in the transit industry are the income-leisure trade-off and occupational stress. One reason for the lack of the expected relationship between overtime and absence in the data might be that those two factors affect different operators. As work is chosen according to seniority, the junior operators are more exposed to stress than senior operators, but junior operators seldom have the option of working overtime, since it is offered on the basis of seniority. The senior operators have overtime available, but they are not exposed to the same level of stress as the junior operators. Another explanation might be that because of the relatively high wage rate at the MBTA and the large portion of fringe benefits in total income, employees can afford to buy themselves more leisure time without making up for the lost income with overtime.

Finally, other factors that affect operator absenteeism, such as disciplinary policies or attendance awards, are not included in this analysis because they are the same for all employees of the MBTA. However, such factors may militate against absenteeism no matter how much overtime is available.

OVERTIME-RELIABILITY RELATIONSHIP

Open work occurring at any time will result in either missed service or overtime, with the split depending on the availability and willingness of operators to work overtime. Accordingly, there should be a relationship between the amount of open work and the resulting reliability, where reliability is defined as the percentage of scheduled trips actually operated.

It is necessary to understand the relationship between open work and missed trips if the reliability concern is to be included in the work force planning process. These relationships, which exist at the operational level of the problem, can have a significant impact on the best strategic-level solution. Hickman et al. (*5*) and Shiftan and Wilson (*6*) showed how to estimate the daily expected open work as a function of work force size, scheduled work, and other factors. Using this function, a relationship between open work and missed trips would enable one to estimate the expected daily number of missed trips and hence service reliability.

The data used for the empirical analysis are for the seven bus garages of the MBTA during the period January 1989 through May 1990. The data were extracted from manpower utilization reports that are completed weekly by each garage manager. From these reports daily figures on hours of overtime worked and missed trips were used to investigate the relationship between open work and missed service. Open work was defined to be the sum of total overtime worked and missed trips. On average there were 16 hr of overtime worked, 5.3 hr of missed trips, and 21.3 hr of open work per day per garage.

In the model systemwide missed trips are estimated as a function of the systemwide open work. Since open work is defined to be the sum of missed trips and overtime worked, missed trips appears both as a dependent variable and as an explanatory variable. The method of instrumental variables was used to overcome the bias and inconsistency otherwise associated with using ordinary least squares in such cases.

Figure 2 shows the different observations, where each observation is 1 day, and the following linear model that best fit the data:

$$MT = 0.248 * OW \qquad (R^2 = .58)$$
$$(t = 23.0)$$

where OW is the systemwide daily hours of open work and MT is the systemwide daily hours of missed trips. Both constant and quadratic terms were insignificant in adding explanatory power to the model.

The results show a strong linear relationship between systemwide open work and the number of missed trips, although it is expected that as the level of open work increases, this relationship will no longer be linear. At some level of open work most operators will be satisfied with their level of overtime, and so it will be increasingly difficult to find an operator who is willing to take on additional work, as operators become more selective in accepting overtime.

WORK FORCE PLANNING ALGORITHM

Total transit operator work force cost includes overtime pay, regular wages, and fringe benefit costs. For a given work force size the determination of regular operator costs (wages and fringe benefits) is relatively straightforward, but the estimation of expected overtime is quite complex. The difficulty arises from the fact that some open work is completely unpredictable since it is not known which operators will be absent from work and, as a result, when extra work will be required. Consequently, overtime is a function not only of extraboard size but also of the incidence of open work over the course of a day and the utilization rate achievable for extraboard operators.

Direct incorporation of all the factors that affect overtime in a single analytical model is very difficult, so Hickman et al. (*5*) developed a semiempirical model consisting of two terms: an analytical term and an empirical term. The analytical term represents regular overtime, and the empirical term [modified by Shiftan and Wilson (*6*)] represents excess overtime. Regular overtime is the minimum overtime possible, given a fixed extraboard size, under ideal conditions. In other words it is the overtime resulting when the extraboard is fully

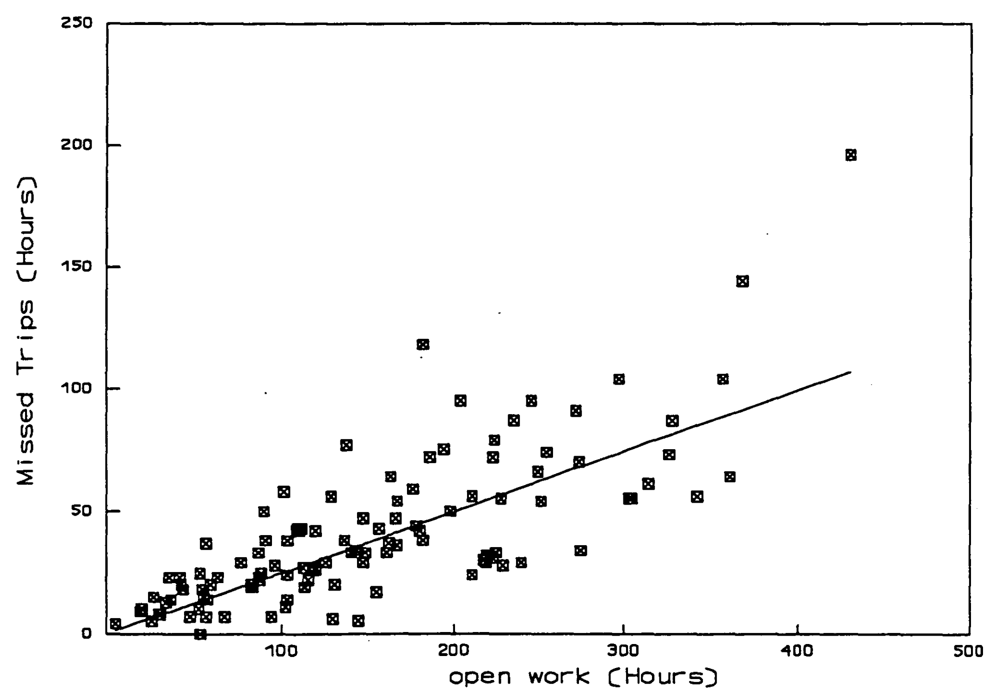

FIGURE 2 Missed trips as a function of open work.

used to meet required extra work, and only work over and above the extraboard size requires overtime.

Since the time of incidence of some open work is completely unpredictable, overtime may be required even if the total amount of required work is equal to the number of available operators. Even if the available cover is optimally allocated over the day, because the times of occurrence of open work are uncertain at the time that cover duties are assigned, it is quite likely that on the same day that overtime will be needed to cover some open work, all extraboard operators will not be fully used (*18*). Excess overtime captures this inevitable imperfection in assigning extraboard personnel to open work and approximates the difference between the actual and regular overtime.

Constraints

With this empirical approximation the strategic work force planning problem can be formulated as a constrained optimization problem with minimization of total annual expected work force costs as the objective.

Five basic constraint sets are included in the optimization problem. The first constraint set defines the number of full-time and part-time operators available in each period, as a function of the hiring decisions and the vacation allocation. The second constraint set represents the contractual limit (if any) on the maximum ratio of part-time to full-time operators. The third constraint set requires that the total hiring across all periods equals the total expected attrition, based on the assumption that the system is in steady state. The fourth constraint set guarantees that the vacation allocation satisfies the vacation liability for both part-time and full-time operators. The final constraint set guarantees that the expected overtime hours used in any period do not exceed a certain percentage of the total required work hours in that period. This constraint is included to ensure service reliability as described earlier. Additional constraints may be defined by each agency according to their policy or labor contract.

The strategic level model thus consists of a nonlinear objective function and nonlinear constraints. Hickman et al. (*5*) used a nonlinear optimization package (MINOS) to solve this problem. In this research a two-stage heuristic algorithm has been developed to solve the problem by decomposing it into multiple single-period subproblems and a simplified multiple-period problem as shown in Figure 3. The single-period problem is to find the optimal number of operator hours for each period using the exact objective function but making some assumptions on the vacation allocation over the year and the ratio of part-time to full-time operators. If the optimal number of operator hours does not satisfy the overtime or reliability constraints, it is raised to meet these constraints. The multiperiod problem is to find a feasible solution satisfying all the problem constraints with a linear objective function minimizing the differences between the actual operator hours available for each period and the optimal single-period results. This approach results in significant simplification of the problem. The algorithm can readily be implemented on a personal computer, making the model easier to use within an agency as well as capable of solving larger problems.

MBTA Case Study

A case study based on the MBTA bus system shows that the solutions obtained by the heuristic algorithm are extremely close to those obtained by MINOS with a maximum difference in total work force costs of less than 0.5 percent (*6*). It is, therefore, reasonable to conclude that the simplification in the problem formulation does not come at an unacceptably high cost in terms of solution quality.

The model described in this paper can be used to evaluate different work force management strategies and policies. The type of issues that this model can usefully address by calculating expected costs and other implications are alternative hiring plans, alternative vacation allocations across the year, impacts of changes in vacation liability, and changes in the reliability objective and in the ratio of part-time to full-time operators. Some of these issues are not solely in the management domain since they are subject to collective bargaining. In this case the model can be valuable by determining the cost of different strategies in order to consider the relative merits of different options during the collective bargaining process.

The intent of this case study is to show the potential use of the model in helping management with strategic decisions, mainly concerning the use of overtime and its effect on system reliability and cost. This case study is loosely based on the bus system of the MBTA.

Constant Hiring and Constant Vacation

Four scenarios, all of which reflect plausible management policies on hiring and vacation allocation, are tested in this section. These scenarios are

1. No additional constraints (the base case),
2. A constant level of hiring in each period,
3. A constant allocation of vacation over the year, and
4. A constant vacation allocation and constant hiring per period.

For all four cases a 1.5 percent overtime constraint was applied, which is the current rate of overtime in the bus system of the MBTA.

Table 2 shows the most important results for the four scenarios including the work force size (average full-time and part-time operators available for work, excluding operators on vacation), expected overtime as a percentage of scheduled hours, expected costs (schedule, overtime, and total), and expected reliability. The results show that the constant hiring constraint alone does not impose additional cost. Although the hiring plan is different, compensating adjustments in the vacation allocation remit in the same hours available for work for all periods in both scenarios. These two scenarios suggest that multiple optimal solutions may exist. This is characteristic of the specific MBTA cost characteristics, work rules, and management policies and may not hold for other transit systems.

The constant vacation allocation case requires more operators and increases the total cost from \$97.8 million to \$99.6 million, an increase of 1.8 percent. Combining the constant

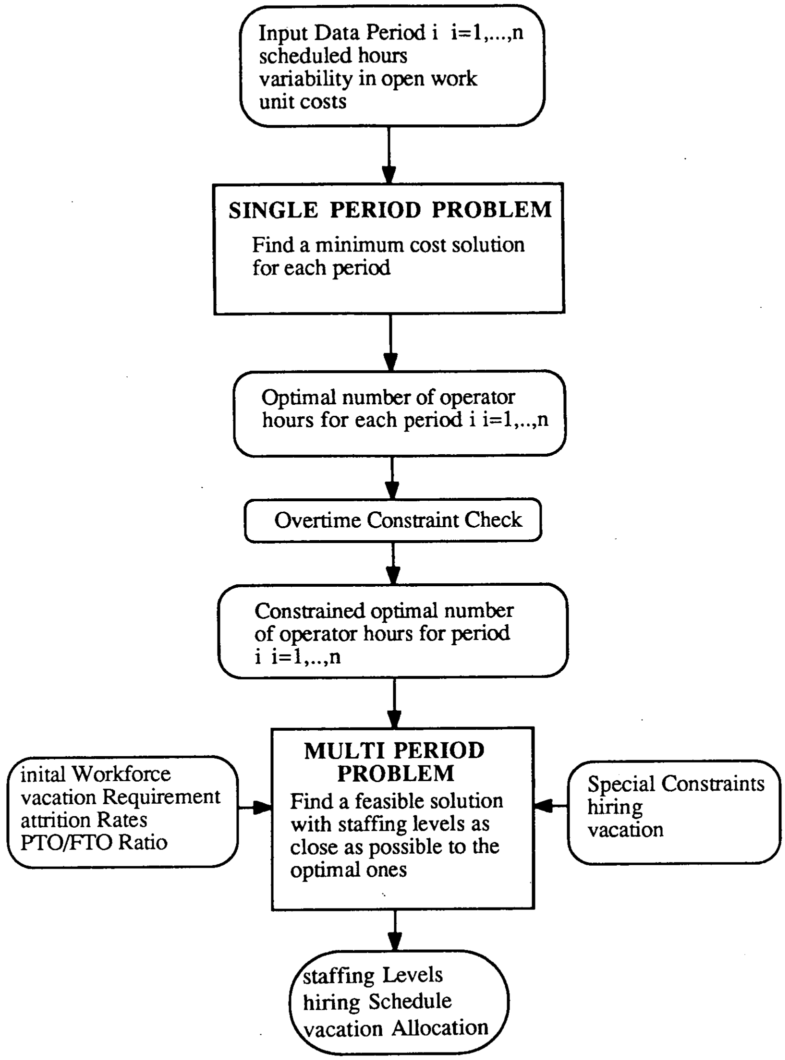

FIGURE 3 Work force planning algorithm.

vacation and constant hiring constraints further increases the total cost to $101.2 million. It should be noted that the cost increase is a result of a higher level of manpower and therefore a higher level of reliability is obtained. The total cost is only labor cost and does not consider unreliability costs. Incorporation of unreliability cost would require a study of the monetary value of unreliability, which is beyond the scope of this work.

This case demonstrates the value of the model by showing that inappropriate vacation allocation may have a high cost. Whereas in the unconstrained case the model makes use of the reduction in scheduled hours over the summer by allo-

TABLE 2 Results of Constant Hiring and Constant Vacation Constraints

	base case	constant hiring	constant vacation	constant hiring & vacation
FT oper	1256	1256	1291	1316
PT oper	654	654	666	685
overtime (%)	1.5	1.5	0.9	0.3
ot cost *	1.4	1.4	0.9	0.3
reg cost *	96.4	96.4	98.8	100.9
tot cost * (%)	97.8	97.8	99.6	101.2
reliability	99.6	99.6	99.8	99.9

* *All costs are in millions dollars*

cating more vacations to it, constant vacation allocation is inefficient.

Sensitivity to Overtime/Reliability Constraint

A set of cases was run to investigate the impact of different constraints on overtime and, by implication, different levels of the reliability objective. Table 3 shows the results of these runs. The first column repeats the results for the base case of the 1.5 percent overtime constraint, and the second column shows the results without any constraint on overtime. The minimum-cost solution is obtained when 12.2 percent of the required work is expected to be covered by overtime. In this case the overtime cost is higher but regular cost is lower, resulting in a net annual savings of $1.3 million (1.4 percent). However, one implication of the increased overtime is a significant reduction in reliability from 99.6 to 97 percent. It should be noted that this level of overtime is well beyond the range of data used in estimating the reliability model, and actual reliability is likely to be even lower.

The third column of Table 3 shows the result for an overtime constraint of 1 percent. Total cost increases by $0.4 million (0.4 percent) and reliability increases from 99.6 to 99.8 percent. In other words, missed service is cut in half, a cost increase of 0.4 percent. The fourth column shows the results for a 5 percent overtime constraint, which are intermediate between the base case and the unconstrained case in term of both cost and reliability.

SUMMARY

For a strategic work force planning model to be realistic, applicable, and useful for transit agencies it should recognize the potential importance of labor supply issues. In this paper the relationships between absence, overtime, and reliability have been studied for the MBTA. Such relationships can have important implications on transit management policies and strategic planning since the availability of overtime is a direct function of strategic work force planning decisions. Specifically, these relations are important in determining the optimal size of the extraboard.

To study the relationship between overtime and absence a disaggregate model of absence was developed as a dynamic form of motivated behavior, a problem in time allocation across activities. This model was estimated with panel data of surface transit operators from the MBTA to test the hypothesis that widespread availability of overtime may induce absence. The results suggest that absence is more a habit than the result of a decision process based on overtime worked. If this is so, reducing overtime will not necessarily reduce absence, and the key to reducing absence may be a system that predicts which employees tend to be absent.

The relationship between overtime and reliability was studied using aggregate data from the MBTA bus system. The results show a strong linear relationship, which makes it possible to include reliability constraints in the strategic problem by setting an upper limit on the amount of overtime that can be planned for any period.

A two-stage heuristic algorithm has been developed to solve the work force planning problem by decomposing it into multiple single-period subproblems and a simplified multiple-period problem. This approach results in significant simplification to the problem so that the algorithm can readily be implemented on a personal computer.

A case study based on the bus system of the MBTA shows the potential use of the model. The impacts of various policies that the MBTA might consider—such as constant hiring increments on a periodic basis, allocating vacations according to a predefined pattern over the year, or limiting the amount of overtime required in any period to a specified level—were analyzed using the model and considering both cost and system reliability. Sensitivity analysis showed the validity of the model and the algorithm for a range of parameters and the effect of different parameters on the solution. This set of analyses makes clear the value of such a model both in ongoing work force management and in policy formulation. The model has been applied to the MBTA, but its structure is flexible and can readily be transferred to other agencies and accommodate different work rules and policies.

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TABLE 3 Results for Different Overtime Constraints

	base case 1.5% ot	no ot const	1% ot const	5% ot const
FT oper	1266	1104	1267	1202
PT oper	654	575	660	625
overtime (%)	1.5	12.2	1.0	5.0
ot cost *	1.4	11.8	1.0	4.8
reg cost *	96.4	84.7	97.2	92.2
tot cost *	97.8	96.5	98.2	97.0
reliability (%)	99.6	97.0	99.8	98.8

* *All costs are in millions dollars*

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Development of Ideal Model for Identification of Rural Public Transit Needs

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As part of a statewide multimodal planning effort, Indiana recently undertook the development of a procedure for estimating rural transit needs in each county of the state. A ridership model based on small urban areas in the state was used along with average fares and costs to generate total revenues, operating costs, and subsidies. A computerized analysis system developed during the research allows the evaluation of different service scenarios.

The state of Indiana is in the process of preparing a multimodal transportation system plan. One part of that plan will address the rural public transit needs of Indiana. This paper summarizes the research undertaken to identify these needs. A more detailed report is available elsewhere (*1*).

The paper has three major parts. The first section identifies the model used to estimate rural transit demand. The second section notes the procedure developed for estimating the supply of rural transit service to be offered and the operating costs and subsidies for this service. The third part discusses estimates derived under two sets of assumptions. The primary goal is not to provide an operating system for a single county, but to provide state-level analysts with a picture of potential rural transit operations across all counties in the state.

ESTIMATING RURAL TRANSIT RIDERSHIP

An insufficient number of rural transit operators in Indiana necessitated the use of an exogenous model for estimating rural transit ridership. A recent analysis of transit demand for small urban areas in Indiana identified ridership as being a function of the size of the transit network, the population over age 55, and local economic conditions (*2*), as measured by "monthly contract rents." This variable is collected by the U.S. Census Bureau and is available for political units ranging from small towns to counties and states.

The small urban area model developed was based on an analysis of the 13 smallest transit operations in the state of Indiana. The explained variation from this model was 98.6 percent and the model had the form

$$\text{Ridership} = 22.23\ \text{POP55} + 849.6\ \text{SYSKM} - 330\ \text{CONRENT}$$

where

POP55 = population 55 and older,
CONRENT = local (county) monthly contract rents, and
SYSKM = size of transit network (km).

Two of the variables necessary for estimating ridership, POP55 and CONRENT, are identical to those used in the urban transit research noted earlier (*2*). SYSKM is not as easily identified as it is in the urban context. Given such an estimate of ridership from the preceding model, annual revenues were estimated as the product of ridership and an average (default) fare value of $1.00.

ESTIMATING OPERATING COSTS AND SUBSIDIES

A computer program entitled RURAL was written to assess operating costs. The user of the program has the flexibility of changing default values for most of the variables including headways, hours of service, speed, operating costs per kilometer, and proportion of network to be served each day. RURAL uses the default or revised values for these variables to estimate daily kilometers of transit service and annual revenue kilometers. The variable daily kilometers of service is the product of the proportion of the system served each day, the maximum size of the transit network (in kilometers), the reciprocal of average headways, and the daily hours of service. The value for annual kilometers of service is the product of daily kilometers and operating days per year (here taken to be 260). Annual operating costs are the product of the average operating costs per kilometer and the annual kilometers of service. There are more precise ways of estimating rural transit costs, but most of these require data that were not available in Indiana (*3*). Operating subsidies (profits) are equal to annual revenues less the annual operating costs. The procedure also estimates vehicles needed as the daily kilometers of operation divided by the daily kilometers per vehicle (the product of hours of operation and speed), and adds to this a 10 percent backup fleet.

Since any county or state road within a county can have people living along it, there is reason to believe that all of these should be served by rural transit. Although it is reasonable to exclude Interstate highways and toll roads, there is certainly no reason to assume that some of the other roads should be excluded a priori, except for counties with urban

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transit, where the urban kilometers of roads and highways would be excluded.

It should be apparent that some very large transit operations would be in place if the road lengths suggested were used. Systems with networks of 1100 to 1300 km (700 to 800 mi) would not be uncommon. With normal headways of an hour, annual revenue kilometers would run from 3 million to 4 million (2 million to 2.5 million mi). This is not unreasonable for urban public transit [Indianapolis has revenue kilometers in the range of 9.7 million (6 million mi)], but the density of population in rural areas is such that the ridership would not be sufficient to merit such a high level of service. There are two solutions to such a predicament: significantly reduce the size of the system to be served or significantly increase demand.

As noted earlier, there is no way of easily reducing system length before laying out the actual routes to be used. In addition, it may not be possible to increase transit demand. However, it may be possible to focus the demand. An earlier study found that transit service attributes had little impact on ridership (*2*). It is believed that this is due in part to the dominance of older riders on public transit systems. This is particularly so in small cities and rural areas, where the 55-and-older age groups are the dominant users of public transit. These riders will adjust their schedules to use the service when it is provided. In effect, these individuals "consume" transit when it is offered. Given that this is so, it is reasonable to assume that most rural transit demands could be satisfied if service were offered 1 day a week. On that day a high level of service would be offered with 1-hr headways through 12 hr of the day.

This scheme would also have the effect of reducing the variable portion of operating costs by 80 percent. It would have no impact on fixed (e.g., administrative) costs. All roads in the county (except those served by urban public transit) would be served once a week instead of five times a week. This would bring the operating costs to a level that would be more manageable for most counties. The county would be divided into five small systems, each covering about 20 percent of what could be called the residential roads there. Many configurations for such service are possible. Examples of two such service patterns for 5 days of operation appear in Figure 1. Of these two, the second appears to offer a higher level of access across the region. Actual configurations would be influenced by the county's network of roads to be served.

Such a system does not provide a full rural transit service. It would not serve the needs of commuters or students, who require daily service, nor would it provide service between all parts of a county. The assumption is that transit service is being provided to a central area, perhaps a county seat, so that elderly individuals would have access to medical care, social organizations and services, banking and legal services, shopping, and so forth. The methods are capable of examining other spatial and temporal service patterns.

This is the basic model proposed for providing transit service to the rural areas of Indiana. Each application is based on a county, although it may make sense to consolidate counties in some cases. Several other assumptions have been made with regard to the service proposed. As noted, it is assumed that the average fare for rural transit service is $1.00. Each subsystem would be served during 12 hr with headways of 1 hr on the day that it receives service. It is assumed that the average speed of buses will be 35 mph. Given that these are state and county roads, with occasional stops for passengers, this is not unreasonable. Finally, it is assumed that the average operating costs per kilometer are $1.93 ($3.12/mi). This value is the average operating cost per unit of distance for all transit (urban, rural, and demand-responsive) service in the state in 1990; it is reduced in a second scenario examined later.

The analysis also estimated capital equipment needs based on kilometers to be served and vehicular speeds. Only vehicles were considered. The analysis has incorporated an average size bus for this service with an estimated cost of $45,000/unit. The needs of areas may differ, and to alter the vehicular capital costs, the number of units should be multiplied by the alternative unit costs to estimate the cost of vehicles. There are no cost estimates here for shelters or maintenance facilities. There may be very little need for shelters, but maintenance facilities would have to be factored into the analysis. Given the number of vehicles involved, it seems that regional maintenance facilities would be the most desirable.

RESULTS OF ANALYSIS

Estimated operating costs across the 92 counties are not highly variable. This finding is consistent with the relatively uniform area of Indiana's counties and the road networks that traverse them. In addition, the type of service proposed is the same across all counties; transit service would cover 20 percent of the network on each of five days a week.

Subsidies for these county operations generally range from $1 million to $2 million. A dozen counties have estimated subsidies under the $1 million level; nine counties would require a subsidy in excess of $2 million. The subsidies per trip range from $2.00 to $7.00. This subsidy level is consistent with existing rural and demand-responsive services in Indiana. The latter have an average subsidy of $4.50/trip.

It is of interest to examine what would happen to total costs, revenues, and subsidies if transit fares increased or costs decreased. It should be obvious that a $0.50 increase in fares will increase revenues by 50 percent (since the assumed fare is $1.00), assuming no ridership is lost due to the fare increase. Since revenues are small in comparison to operating costs, this type of change has little impact on subsidies. On the other hand, decreases in operating costs can significantly decrease the level of subsidy. As an illustration, bear in mind that

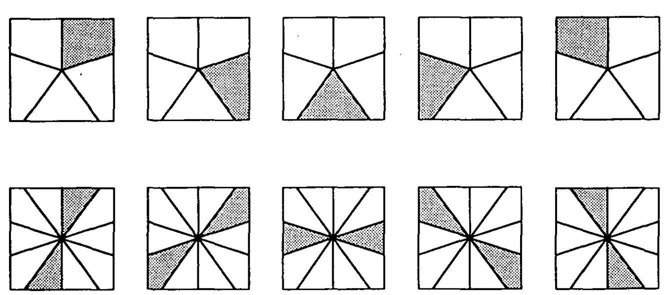

FIGURE 1 Two seats of idealized service patterns for 20 percent coverage 5 days a week.

subsidies can never exceed operating costs. Therefore, reducing operating costs by a third or a half will drop subsidy levels by at least that much in the absence of any revenue. If revenues are present, the decrease is even more significant. For example, assume an operation has a $1 million operating cost and a revenue base of $200,000. This results in a subsidy of $800,000. A 50 percent decrease in operating costs results in a 62.5 percent drop in the subsidy.

It is easy to assess the impact of single-variable changes on the rural transit financial picture for each county; simultaneous changes in fares, hours of service, and operating costs are more difficult to estimate. It is problems of this type that RURAL was set up to examine. For example, assume that fares will increase by 50 percent (from $1.00 to $1.50), the hours of service will be cut back by 16.6 percent (from 12 to 10 hr each weekday of service), and operating costs per kilometer will be reduced by 33.3 percent (from $1.93 to $1.29). Although it has not been used here, one could assume that the Simpson-Curtin rule (*4*) is operative with change in fares. That rule suggests a 15 percent drop in patronage with a 50 percent increase in fares. If we had a better idea of a proper average fare, then we would know if such adjustments were merited.

For this second case, there is an increase in revenues of 50 percent. Operating costs have dropped in the range of 30 to 45 percent. The subsidy has dropped to an overall average of $570,166. Considering current subsidies in the state, this subsidy level would suggest that at least several of the operations may merit further review by the counties involved since they may be paying subsidies at this level for a less attractive service.

CONCLUSION

This research effort has identified a procedure for examining the potential costs, revenues, and subsidies of rural transit operations across all counties in a state. In the process several questions for future research in the area became apparent. How does one identify a rural transit network? How elastic are fares in the rural context? Does fixed-route service of the type envisioned here have a role in rural areas? Progress in this field requires better data as well as further research.

ACKNOWLEDGMENT

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Design and Analysis of Advanced Transit Systems Using Interactive Computer Animation

ALAN L. ERERA AND ALAIN L. KORNHAUSER

The Princeton Intelligent Transit Visualization System (PITVS) is described. The PITVS is software designed to provide transit planners, engineers, and the general public with an interactive three-dimensional transportation system design and analysis tool. The software provides the functionality to (a) build transit networks, positioning guideway, intersections, and stations while specifying guideway cross-section characteristics and station demand characteristics using a graphical user interface; (b) view these networks in a three-dimensional representation of the planning area with fully interactive user control over viewing positions; and (c) view randomly generated simulated operations on a transit network design based on demand characteristics and a system operations strategy. Both the methods of and the motivations behind the PITVS are explained, and the positive enhancement that interactive three-dimensional graphics will give to the transit systems design process is affirmed.

Mass transit is a public service: researchers, planners, and engineers do not create a transit system for colleagues to study in a laboratory—they build the system for the public. The design of any mass transportation system must take into account the desires of the community and its public officials as well as the engineer's assessment of the community's transit needs. Any proposal for a new transit system will meet with public scrutiny in many areas; a design that is not amenable to the public will probably never gain enough social and political acceptance to be built. It is up to planners, therefore, to prove to the public both the necessity of the transit system and the adequacy of the proposed system for solving the transportation problem.

It is usually not an easy task to convince community members that a proposed transit system is an acceptable solution to their transportation problems. Questions almost always arise over the costs of a transit system: the financial costs of a system and the impact costs that a system may inflict on the environmental and socioeconomic conditions in a planning area are crucial issues. Today's planning efforts are systematic approaches that take considerable pains to relay important information about such costs and effects to the community for which a system is being planned. The more information that is available to planners, decision makers, and the public, the more successful any planning effort is likely to be. One of the most exciting new forms of information that can be made available for transit planning is three-dimensional computer visualization.

The state of current computer hardware and software technology offers the opportunity for the analysis of much crucial visual information concerning proposed transit systems far before any physical construction takes place. The powerful graphical capabilities of the personal workstation make possible the three-dimensional viewing of transit system designs in a modeled planning world. The processing power of the workstation furthermore offers the possibility to view this visual information dynamically; users are not limited to a "fixed view" of the modeled world, but they can look at the state of the system at any instant in time from an almost infinite number of perspectives.

The Princeton Intelligent Transit Visualization System (PITVS) is an initial attempt to provide this new level of planning information to designers, engineers, decision makers, and the public. Using the power of user-interactive three-dimensional graphics, the software system provides an advanced visualization tool that can aid both planners and the public in sorting out many of the complex visual impact issues posed by any fixed mass transit design. Thanks to the speed of the modern personal workstation, the PITVS can readily provide on-screen visual comparisons of a variety of user-specified system layout designs and give the user a peek at what a true implementation of a transit system may look like before it is built.

PITVS DESIGN CONSIDERATIONS

The PITVS began as a term project for Princeton University's introductory transportation systems course and has since been enhanced and retooled. Major enhancements intend to improve the both the visualizations provided and the flexibility of the system. Developed with the philosophy of using the latest technology in personal workstation computing, the PITVS is designed to enhance the transportation planner's design task in a way not previously available: through the use of interactive three-dimensional computer graphics. Earlier efforts in the use of interactive computer graphics for the analysis of transportation problems are documented by Kornhauser (*1*). These efforts typically focused on problems in transportation data analysis, but the PITVS is a step forward in the use of graphics for transportation design visualization.

The system model in its current implementation has been written in the C programming language under the Unix op-

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erating system for use on Silicon Graphics personal workstations. These workstations are especially powerful for graphics because of their use of specialized graphics hardware engines and support for a large software library of graphics routines. Although the processing and graphical power of such machines is great, it is not without limit, and therefore reasonable constraints are placed on the realism of the PITVS visualization.

The background environment in which the transit system is placed and visualized by the user is designed with the goal of providing reasonable realism without overburdening the system hardware. Since user-controlled, dynamically changing views are considered essential to the system, the realism of the background is somewhat limited to allow for instantaneous screen refreshes. Of course, modeling a real-world setting could be infinitely complex; limiting the realism of this background environment model entails drawing only the components of the modeled world that are necessary for an adequate visual analysis.

Currently, the system requires as input three-dimensional geometric descriptions of buildings, roadways, and any other prominent natural and physical structures necessary for the adequate modeling of a planning environment. The time spent on forming this geometric background representation should be on the order of tens of man-hours for an average-size planning area. The geometric data are currently required as a sequence of vertex coordinates for use in polygon drawing routines; future improvements will allow users to create and modify such data through an interface and possibly support importing such data from popular computer-aided design (CAD) packages. The background views offered by the PITVS provide a sufficient representation of reality without detracting from the performance of the system. With the development of faster computer hardware, the realism of the background view can be enhanced to create an even more useful visualization tool; currently, the authors let the user's mind fill in the gaps. It is also important to note that the PITVS does not support modeling ground elevation data in its planning world; this feature is being explored as an enhancement to the system.

To render three-dimensional visualizations of transit system hardware, the PITVS requires a three-dimensional geometric description of the guideway cross section as well as support column and station designs. Fairly simple geometries are required for performance reasons. Whereas the cross section of the three-dimensional guideway is simple, the guideway is allowed to curve between user-defined placement locations (hereafter called nodes). Curving guideway was considered essential to represent turns and intersections adequately. The representation of the transit stations could also be fairly basic in order to limit the number of polygon draws that the system must execute. A simple platform and shed structure next to the guideway and a shaft structure extending to the ground representing an elevator shaft or stairwell are used to represent graphically the stations in our demonstration system. The PITVS also allows the visualization of transit vehicles on the guideway. Once again, the geometric descriptions of the vehicles are kept simple. On the demonstration system, for example, each vehicle consists of only a few polygons pieced together to form a box-like car representation.

The relatively simple geometric design of the three-dimensional modeling world is intended to enable the system to refresh the screen in real time as the user views the transit system design from many viewpoints. Viewing a single transit design from multiple points is not enough, however. The PITVS can also change quickly between different network layouts in the visualization, and thus it easily allows comparable analysis. Another common situation would be one in which the planner decides that a guideway alignment may look better if it were altered slightly. Easy-to-use network editing functionality for creating and altering network designs is therefore also provided as one of the key tools of the software. Thus, the PITVS provides an adequate platform for the visual comparison of alternative transit networks, and any changes to a network created with the network editor can also be visualized quickly.

Finally, the PITVS allows users to view a transit system design not only at a single point in time but also as a dynamically changing system in a three-dimensional visualization of simulated operations. Again, flexibility in controlling the visualization was a paramount design criterion. The PITVS lets the user view operations on the same system with different user-specified demand situations. Special viewing perspectives are offered for viewing a transit design with simulated operations. Once again, excessive detail is spared in the simulation to allow for flexibility and user control over simulated operations; although the demand information is generated fairly simply and the control algorithms for the vehicles are not incredibly sophisticated, the simulation provides yet another bank of visual information for the user to analyze.

PITVS SOFTWARE COMPONENTS

Overview

The PITVS software model provides three main areas of functionality, shown graphically in Figure 1. The first set of functions allows the user to create, modify, store, and retrieve

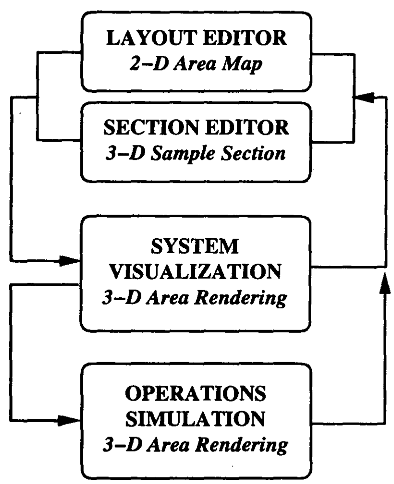

FIGURE 1 PITVS functionality flow chart.

transit networks to be used in the visualization. Next, the main group of functions allows the user to visualize a transit network design at a fixed point in time as part of a three-dimensional world. The third area of functionality allows the user to set up a variety of simulation parameters and then view simulated operations over a network design in what is essentially a dynamic, real-time visualization of the state of the transit network.

The PITVS can provide three-dimensional visual information for any fixed-guideway mass transit system. As a demonstration of the software, the authors chose to model the system characteristics of personal rapid transit (PRT) and to attempt to visualize several system designs for the Princeton University campus. Advanced mass transit system design is seen as one of the potential applications of the PITVS software. An advanced visualization system such as the PITVS offers a fairly detailed preimplementation view of any transit system design; this can be especially useful for advanced transit that may have questionable visual impacts and misunderstood operational characteristics due to the lack of existing example systems. Public acceptance of the visual impacts of elevated guideway has long been a problem for PRT; almost 20 years ago, Lutin wrote that "the major considerations in determining the guideway route arise from aesthetic and environmental conditions" (*2*,p.36). Certain operational characteristics of PRT systems also transfer well to this demonstration of the animated viewing of simulated operations. Automated service means, of course, that in an actual implementation computers would be controlling the movements of vehicles; such a situation lends itself nicely to a computer simulation of operations.

The Princeton campus and PRT having been chosen for demonstration, the first step in using the PITVS is to generate a geometric description of the planning world as well as the general guideway cross sections, support structures, and station structures. Currently, this information is read from file at run time and not altered during the operation of the software; this is simply the current implementation and is by no means a necessary constraint. Once these geometric data have been processed, the user can begin a planning and visualization session.

Visualization Functionality

The user-interactive visualization functionality is the true power of the PITVS. After retrieving a transit network from disk or creating a network using the network editor (to be discussed shortly), the user clicks a single button on the on-screen control panel to transform the view from a flat two-dimensional editing tablet into a window on a three-dimensional world. Figure 2 gives an example of a view created with the PITVS. The sample depicts an elevated monorail-type guideway weaving among buildings of the Princeton campus. Users can now activate the zoom feature on the control panel and use the mouse to "fly" anywhere in this world, watching the view dynamically changing as they move the mouse in different directions. The flexibility is available for the users to position

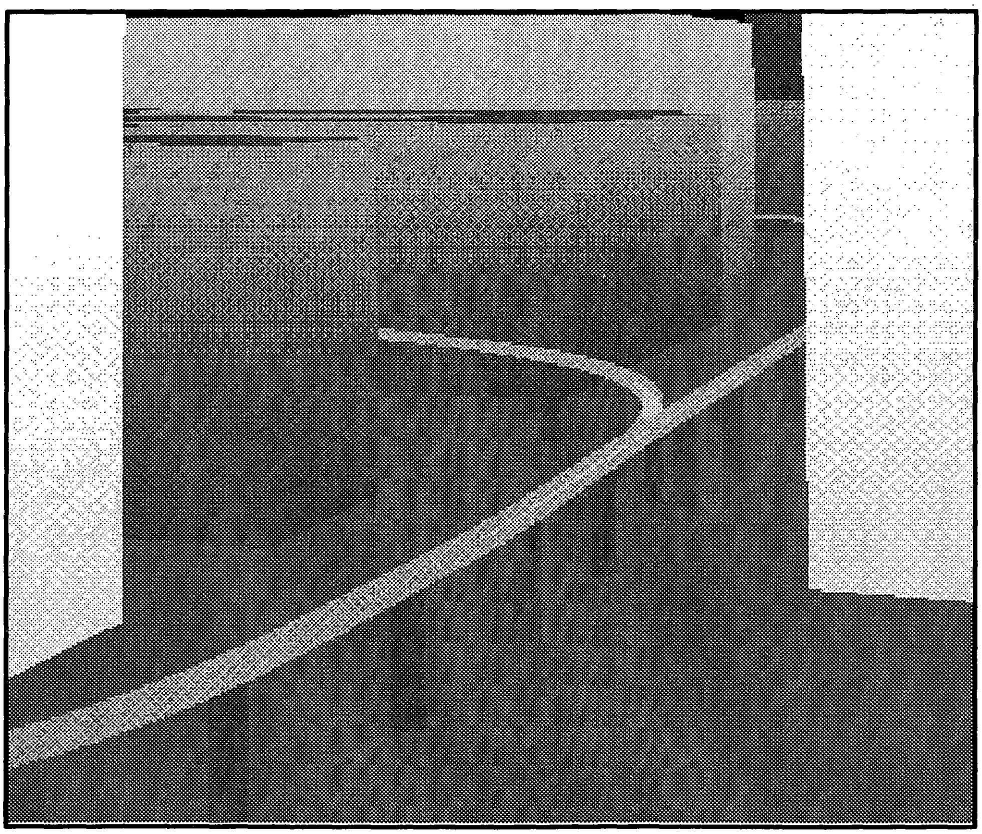

FIGURE 2 Sample PITVS visualization.

themselves virtually anywhere in, around, or above the world that they have just created. To view this world effectively without noticeable delay between redraws, several advanced features of the graphics workstations are used. The Silicon Graphics machines support a drawing method known as double buffering in which an entire scene is drawn into an invisible buffer that is then made visible by "swapping" buffers. Using this method, the PITVS can create smoothly changing views as the user zooms throughout the three-dimensional scene.

The view itself is created by a series of multicolored polygon draws. The background environment of buildings, roads, and other features is drawn first. Once the background is drawn, the software renders the user-defined transit network. To create a smoothly curving guideway, a mathematical splining algorithm is used; Figure 3 illustrates the Cardinal spline curve. The position of the guideway is defined by a number of nodes (the numbered circles in Figure 3), and the curving guideway is created by generating a number of sequential control points (the gray squares) through the use of this mathematical algorithm. The guideway is then rendered as straight segments between these control points. A forward difference algorithm is used to create the control points for the parametrized curve (*3*). To improve the PITVS, work is under way to allow the user to specify minimum curve radii for the guideway design and provide constant radius curves as guideway options. The current implementation uses curve fitting only for simplicity; more advanced alignment modeling techniques are being explored.

Once the control points for the guideway have been determined, they are stored with the other transit network information and are not recalculated unless a change in the network is made. The three-dimensional guideway segments are drawn between these control points. Although each segment is straight between control points, the guideway image truly appears to curve; a greater number of control points will produce a more smoothly curving guideway. When the user has specified elevated guideway, support columns are drawn to the ground underneath the guideway at evenly spaced intervals. After drawing the guideway and columns, the program renders the stations. Since the demonstration system is currently oriented toward PRT, the stations are drawn offline, paralleling the guideway at the same height. Station platforms and housings are then drawn next to the guideway. To model a PRT system accurately, the length of the off-line segment used to represent a station is made a function of the station's vehicle berthing capacity.

After the completion of the polygon draws for the background, guideway, and stations, the buffers are swapped and the three-dimensional image appears on the screen. It is important to realize that almost every polygon must be redrawn each time the user changes viewpoint in order to account for the new perspective attained on the scene; more detail, therefore, creates slower redraw speeds and hence less flexible software operation.

Network Editing Functionality

Graphical CAD software packages are readily available for the design of everything from automobile engines to skyscrapers. Although the PITVS does not support many of the advanced design tools that a typical CAD package offers, the software includes tools for graphically laying out a network of transit guideway on a two-dimensional map representation of the design area. Using a palette of on-screen push buttons partially depicted in Figure 4, the user can set and change the guideway position quickly and easily. The guideway is positioned by running a curving line segment through a series of positioning nodes. These node locations can be quickly changed by clicking on them with the mouse and dragging them to new locations. To create a connected network of transit guideway, intersections can be added with guideway segments branching off in other directions. Stations are added at points along the guideway and are given size and use characteristics to be used during the operations simulation. The system assumes certain basic characteristics of the transit guideway, but it does allow the user to edit some of the scaling attributes

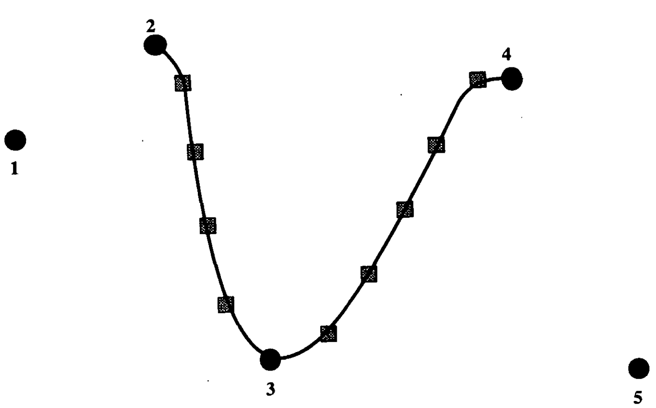

FIGURE 3 Generation of control points using cardinal splines.

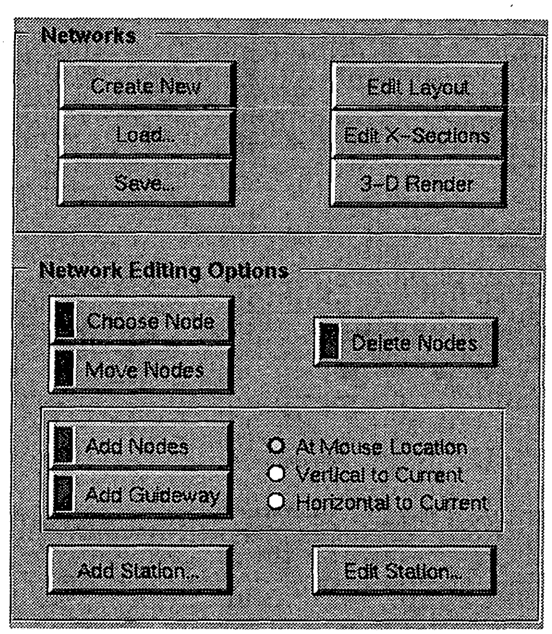

FIGURE 4 Portion of main network editing control pad.

of the guideway cross sections using the push-button palette shown in Figure 5. Simple controls can be used to change the height and width of the guideway deck as well as the height of the support columns; thus the visual impact of a 3-ft-wide guideway and a 6-ft-wide guideway can be compared.

The PITVS software uses the FORMS library of graphical user interface tools as its primary means of interaction with the user (*4*). The FORMS library is public domain software that provides functions for the creation of the control panels and dialogue boxes used in the PITVS. A main control panel is fixed on one side of the screen while the system runs. Nearly all network editing functionality is invoked by clicking with the mouse on buttons on this main control panel and then pointing and clicking over the main program window to add nodes, move locations, and so forth. Certain functions such as adding or editing stations open additional dialogue box areas in which the user inputs information on station capacity and demand characteristics. A status bar area on the main control form is used to give instruction to the user while editing networks.

Designs created with the network editor of the PITVS can be saved to disk and later retrieved and worked on again; the guideway information is stored in text files in a simple format so that any transit network design created using a different system can easily be converted to a form readable by the PITVS. And, any time during the editing process the user can switch to the three-dimensional visualization mode to view the design. By switching back and forth between the editing tablet and the viewing mode, the network designer can fine tune the positions of the guideway, stations, and intersections in the transit design. The network design functionality of the PITVS is not meant as a replacement for detailed alignment sketches or guideway engineering plans. It is intended to be an easy-to-use network editor, however, that allows fairly simple translation of alignment sketches into the PITVS format while also allowing those who are experimenting with the design of guideway layouts to do so in an interactive computer graphics environment.

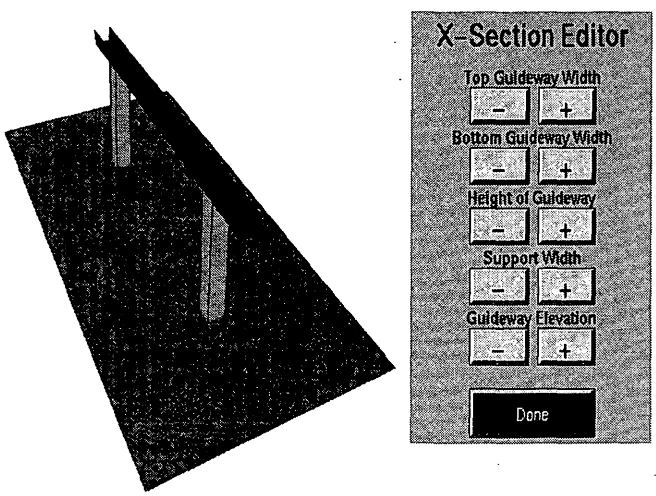

FIGURE 5 Cross section editing.

Simulated Operations Functionality

The final area of functionality provided by the PITVS deals with simulating operations over the user-designed transit network. After editing a proposed transit design on a two-dimensional map and visualizing it at a static time frame in three dimensions, the user has the option of watching a three-dimensional real-time simulation of transit operations once again from a virtually limitless number of viewing points.

The operations simulation has several components. First, an array of patron arrival information is created through a simplified method that assigns a fixed exponential interarrival rate to each station. When building a network, the user is asked to specify estimates of the number of daily vehicle arrivals and departures for each station. This estimate of vehicle departures from each station is then used to determine an average patron arrival rate for that station over a 16-hr operational day. Each station's patron arrival rate is used as the parameter of a Poisson process to generate patron arrivals throughout the day. Because Poisson processes have exponentially distributed interarrival times, an inverse transformation of the exponential cumulative distribution is used for the simulation (*5*). After generating a uniform random number U on [0,1], the exponential interarrival time X is determined by the following equation:

$$X = -1/q \log (U)$$

where q is the exponential arrival rate.

Each arrival patron (or group of patrons) is then assigned a station destination. This destination is generated simply by calculating a relative attraction factor for each station on the basis of the user-supplied information about the daily number of vehicle arrivals and, from these attraction factors, forming a cumulative distribution function for station destinations. Each arriving party is then randomly assigned a destination station using this derived cumulative distribution.

Currently, the generation of patron arrivals and destinations is not time dependent; each station's patron arrival rate remains constant throughout the simulation. Adding sophistication to the demand scenario simulation would probably add value to the operations simulation. Since the simulation is designed to be viewed in real time, however, there may be no need to further refine the calculation of the demand scenario; demand probably remains constant over the 5- to 10-min window that the average planner spends watching the simulation.

Once the patron arrival information has been determined, transit vehicles are assigned to the stations on the network on the basis of user specifications, and then the simulated operations begin. At each time step during the simulation, a system state update occurs in which a number of tasks are executed. First, all of the new patron arrivals are determined for each station in the network on the basis of information in the patron arrival array generated earlier. Queues of patrons waiting for vehicles are updated with this information. Next, passengers are unloaded from occupied vehicles now berthed at their destination stations. Third, patrons waiting in station arrival queues are loaded into berthed empty vehicles that have destinations equal to the patrons' destinations.

The demonstration created for PRT uses some control strategies specific to automated transit design. For example, in PRT operations simulation an empty-vehicle dispatchment algorithm is implemented that attempts to redistribute empty vehicles in a logical away around the network. Destinations for the empty vehicles are determined by an algorithm that calculates excess capacity at each of the stations by subtracting the vehicles berthed at that station and the number of vehicles en route to that station from the station's berth capacity. The empty vehicle shuttling algorithm sends the vehicle to the station with the largest positive excess capacity in an attempt to rebalance the transit vehicles dynamically.

Other control strategies are also implemented for PRT simulations. Vehicles that have been berthed at stations or are waiting in the arriving or departing vehicle queues are moved into open station slots ahead of them or out onto the guideway. Any vehicle in the farthest position in the departing vehicle queue is moved out onto the guideway, if possible; all trailing vehicles in the departure queue are subsequently moved forward one slot, if possible. Once all of the station movements have been completed, the control strategy algorithm turns finally to vehicles moving on the guideway. Each vehicle traveling between stations has been assigned a station destination determined either by the station destination of the passengers riding in the vehicle or by the empty vehicle shuttling algorithm. When the simulated operations are initiated for PRT simulation, the PITVS computes network-spanning shortest-path trees for each station using a label-setting algorithm. The result of this computation is an $(S \times N)$ array of "next-node" information where S is the number of stations and N is the number of nodes on the network. For each station destination and node location of a vehicle, this array tells the vehicle the next node to which it should proceed in order to reach the destination along the shortest path. To control systems other than direct origin-to-destination systems such as PRT, this array of next-node information will no longer be acceptable. To generalize operations simulation, enhancements will include encoding such information specifically for each simulated vehicle so that vehicles having different routes can be used.

Although the current demonstration PITVS simulation algorithms give the user an interesting visualization of a PRT system in action, it is important to note that the goal of the simulated operations was not to provide transit planners with key performance information. Currently, the demand generation and control algorithms are far too infantile for this purpose. Instead, the authors wanted a reasonable approximation of actual operations with calculations simple enough to be performed by a personal workstation in real time. The results have been promising; all of the system state update algorithms are performed along with an entire screen refresh many times each second, providing a smoothly changing view of real-time simulated operations.

PERFORMANCE ENVELOPE

To determine if the PITVS provides a useful visualization tool, it is essential to discuss performance issues. As has been emphasized, any visualization tool must be able to provide access to its visual information with a speed that does not leave the user frustrated and unwilling to continue to use the tool. How fast is fast enough? The PITVS lets the user dynamically change viewpoints with the mouse, essentially flying around the modeled world, and this action requires that the entire screen be redrawn several times every second. Additionally, to update the view of the system state during simulated operations in real time, the scene must again be redrawn at least once a second to be useful.

The PITVS attempts to limit the number of polygons drawn in order to keep the draw speed at a satisfactory level; even these attempts, however, cannot prevent some performance limitations. Performance of the PITVS in terms of redraw speed is a function of the hardware, the size of the user's network design, and the detail of the geometric representations. Most system development was done using a Silicon Graphics 4D/210 workstation configured with VGX graphics. The 4D/210 uses a single RISC 25 MHz processor rated at 3.3 MFLOPS, and the VGX graphics board renders 180,000 polygons per second. Also used were an IRIS 4D/35G with a faster processor rated at 6 MFLOPS but slower graphics, rendering only 6,000 polygons, and a 4D/35 with an Elan graphics board capable of 100,000 polygons. The best performance of the PITVS software was realized during a demonstration on an IRIS with VGXT graphics. Fast redraw speeds provided excellent user control while changing viewing positions in the visualization. As a testimony to the usefulness of the system, several transportation engineers attending the discussion inquired about using the system for visualizing roadway and parking designs for airports.

One exciting hardware development that would greatly enhance the PITVS is Silicon Graphics' newest graphics hardware configuration, the Reality Engine. This powerful system offers real-time texture mapping, a feature that would allow the PITVS to increase its level of realism dramatically. Texture mapping in real time means that images scanned into the computer from color photographs can be displayed on polygons drawn on the graphics screen and can be updated almost instantaneously as the user changes viewing positions. Hence, photographic images of buildings and natural features could be incorporated into the PITVS display to further enhance the visual information that the system provides. Current system development is being done on a Silicon Graphics Indigo2 configured with Extreme graphics.

It is important to comment on the practical size of a three-dimensional world to be modeled with the PITVS. Although completely dependent on the detail of the geometric representations and the configuration of the hardware, the PITVS should be able to render on the order of 10^5 visible polygons on most systems without considerable delay. Visible polygons refer to those that actually need to be drawn on the screen, not those that lie behind the current viewpoint. This threshold should allow adequate visualization of on the order of 1 to 10 mi^2 of a planning area at a time.

CONCLUSIONS AND RECOMMENDATIONS

The state of personal workstation computing today provides the opportunity for advanced three-dimensional visualizations; the PITVS takes advantage of this power to give transit planners, engineers, and the general public a three-dimensional view of proposed transit systems far before implementation. The PITVS provides visual information rarely if ever before available to transit planners and does so with some degree of flexibility. More important, however, the PITVS software may serve as a base platform from which even more advanced visualization systems can be built. What is state of the art in terms of computer hardware today is often commonplace tomorrow; soon, therefore, may be available the necessary processing and graphics power to more closely approximate reality in the PITVS model. An example of a possible enhancement envisioned would be a so-called texture-mapped background environment in which the polygons representing structures in the PITVS scene would be overlaid with actual photographic images. Any reality-enhancing improvements that do not detract from the system speed and flexibility will increase the value of the PITVS. As a stand-alone system in its current state and as a platform for future development, the PITVS provides powerful new information that will help professionals and the public alike in sorting out complicated visual impact issues as well as enhance the transit designer's task.

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