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Foreword

The 30 papers in this Record provide a good cross section of current research in public transportation. They have been grouped into six topics—management, finance, planning, bus operations, rail transit operations, and new technology. Although funding for transit research has been steadily declining in recent years, the quality of research has not diminished. Of special note is that one-third of the authors are practicing engineers, planners, and transit managers, despite the frequently heard concern that research is done primarily by academics with little interest in applicability of findings. The papers in this Record show that this concern is not entirely the case.

Part 1, Management, includes two papers on federal regulations mandating random drug testing and on accuracy of such tests. Litigation and concern by management and labor about program administration will certainly affect the finally adopted requirements of this new program. Early experiences with drug testing programs as reported in these papers serve as a good benchmark against which to evaluate future changes. The other papers in Part 1 report labor management studies conducted to improve productivity. The studies evaluate factors such as contract work rules, absenteeism, fringe benefits, scheduling of extraboard personnel, and standards applied in planning, scheduling, and controlling of maintenance activities.

The first two papers in Part 2, Finance, describe the capital planning process in the San Francisco Bay area. It is shown how a consensus list of capital priorities is arrived at and in what ways the cumulative financial positions of each of the transit operators in the region are affected. The next paper presents a methodology used by the Southern Pennsylvania Transportation Authority in setting the priorities for its capital program. Two papers report cost-savings studies. The first concerns a vehicle replacement methodology developed for the 13 transit operators in the Los Angeles area. The methodology identified cost savings in excess of $117 million over a 10-year period. A second paper shows the benefits of life cycle cost applications in vehicle maintenance activities.

Part 3, Planning, contains seven papers that report transit planning studies. The first paper contains the frequently studied and debated issue of the relative effectiveness, cost, and efficiency of rail and bus transit modes. The Lindenwold transit line with 13 stations was compared and contrasted with the 26 New Jersey Transit bus routes serving the same suburban area of Philadelphia. The next paper presents estimates of net costs of transit trips taken during peak and offpeak periods. It confirms previous findings by other authors that the cost of providing peak-period trips is indeed higher than that of providing offpeak trips. The next paper describes the steps taken by nine jurisdictions north of Seattle to preserve rights-of-way for use by high-capacity transit in the future. This approach promises great savings, because right-of-way acquisition is a major cost factor of any new transportation facility. During the last two decades, a number of cities have considered fixed-guideway transit systems. In the next paper, a conceptual model of the decision process is presented that is based on review of eight metropolitan areas. Two papers present issues relating to design of transit station, stops, and terminals and ways in which to minimize the nuisances of elevated transit stations. Most of the nation's large university campuses have major transportation and parking problems. The last paper in this part reports a case study in land use and parking regulations aimed at supporting increased use of transit.

The first two papers in Part 4, Bus Operations, report studies performed in New York City. The first paper analyzes bus dwell times, passenger service times, and bus capacities for midtown Manhattan. The second paper describes the planning process, bus rerouting to serve the new Archer Avenue Transit Line, and bus operations in the first 6 months after the change. The next paper reports a study of the bus system in Quito, the capital of Ecuador. It was found that coordination among the 36 operators that provide bus service was poor and that there was a strong need to create a planning and executive unit that could oversee all transit operations. The final paper in this group describes a study for identifying measures that could oversee all transit operations. The final paper in this group describes a study for identifying measures that could be used to determine transit systems with superior bus maintenance performance. A data base containing Section 15 information was created for the purpose of designing indicators and peer groups of transit systems. Within the peer groups, transit systems with superior bus maintenance performance were identified.

Part 5 of this Record contains papers covering rail transit design and operations. The first paper describes a subway performance model developed by the New York State Metropolitan Transportation Authority that uses subway passenger experience as a base, measures that are meaningful to riders, rather than the more common performance standards used by operating agencies. The next paper presents a three-step evaluation process used to select the alignments, station locations, and construction method for a Baltimore rail transit extension. The following paper describes the methodology used to evaluate the operating cost savings associated with alternative storage yard configurations and locations for San Francisco's light-rail vehicles. The modernization of the Norristown High-Speed Line located in the Philadelphia suburbs is the subject of the next paper. This light-rail facility, which has been in operation since the turn of the century, is undergoing major capital renovation. The last paper presents several forms of motive power for suburban rail lines considered to help lower initial capital costs.

For developing countries, building a highway transportation system similar to that of the United States would require huge investment. However, there still are opportunities to select a vehicle-roadway system that meets local needs. The first paper in Part 6, New Technology, explores what such a vehicle-roadway system might be. Critical to implementation of any new people mover system for special activity centers is its financial feasibility. The last two papers in this Record examine this issue.The first of these reports a study for the proposed Atlantic City people mover and the second suggests ways of using value enhancement means for financing people movers in suburban major activity centers.

PART 1

Management

Employee Assistance Programs in the Public Transit Industry: Experience of Connecticut Transit and Some Concerns for the Future

DAVID A. LEE

Employee Assistance Programs (EAPs) provide a specific referral for employees whose deteriorating job performance warrants intervention, as well as a source of confidential, low-cost help for employees troubled by any type of personal or family problem. Widespread concern about controlling workplace substance abuse and the advent of drug testing of safety-sensitive employees have focused much recent attention on the role of EAPs. Alternative EAP models, the role of unions in planning EAP services, considerations in program design that impact cost, and selection criteria are discussed. Three particular concerns about the future roles of EAPs include the responsibility for determining employees' fitness for duty, the appropriateness of rehabilitation counseling in all instances of employee misconduct or positive drug tests, and the integration of EAPs with company disciplinary policies.

> There is a man—a bus driver—whose job performance has worsened markedly in recent weeks. He used to have excellent attendance; now he's been absent or tardy to the point that the company's attendance policy would prescribe discipline. Several uncharacteristic complaints about his rude behavior have been received from passengers, and his supervisor notices how this usually cheerful individual has lately become sullen and withdrawn.
>
> Another employee—let's say a woman supervisor—is struggling with devastating problems in her personal life outside the office: an impending divorce, children in trouble at school, financial difficulties. So far, she has managed to keep her problems hidden from her coworkers. Each day, however, as they seem ever more overwhelming, these problems are becoming an almost constant distraction from her job.
>
> And there is a third employee—an otherwise dependable, trouble-free individual—who just tested positive for alcohol or drugs in violation of your company's written policy.

Employee Assistance Programs (EAPs) exist precisely for people such as these. In the first case, EAPs provide supervisors with a specific point of referral for employees whose job performance warrants intervention. Supervisors are trained to deal only with an employee's actual job performance. When performance deteriorates, referral to the EAP may be combined with, or substituted for, normal progressive discipline. The objective is to relieve supervisors from having to diagnose the complex and highly personal problems that may trouble employees on the job.

In the second case, the EAP provides a credible point of contact for employees or their family members seeking help on a confidential, low-cost basis. Clearly, the greatest strength of a successful EAP is the ability to help employees before problems in their lives translate into performance problems in the workplace.

Situations like the third case have recently given the greatest impetus to establishing EAPs in the safety-conscious public transit industry. The advent of federal regulations mandating a drug-free workplace and possible urinalysis testing of transit employees, national concern about substance abuse throughout society, universal adoption by public transit operators of strict (albeit varying) rules prohibiting drugs and alcohol, and other factors have focused particular attention on the role of EAPs in facilitating the rehabilitation of drug- or alcohol-dependent employees (*1,2*).

This paper will outline the development of EAPs in the public transit environment, on the basis of actual experience at Connecticut Transit. Various related issues, including the role of unions and specific considerations for management in developing an EAP, will also be examined. Finally, some specific concerns about future roles for EAPs will be discussed. Connecticut Transit is the principal operator of public bus service in the Hartford, New Haven, and Stamford urbanized areas under contract from the Connecticut Department of Transportation. The system, which employs more than 800 bus operators, mechanics, and office staff in its three divisions, operates nearly 300 buses in peak-hour service.

TYPES OF EAPs

UMTA's recent implementation guidelines for anti-drug programs in mass transit define the EAP as "a program provided directly by an employer, or through a contracted service provider, to assist employees in dealing with drug or alcohol dependency or other personal problems" (*3*). However, this definition barely begins to describe the variety of available EAP models. There is no generic EAP.

At Connecticut Transit, the EAP has evolved considerably during the past 15 years from what was originally a self-help group of employees concerned with alcoholism recovery to a

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broad-brush program using the services of a professional outside contractor. Most employers customize the EAP to suit their particular workforce and the constraints of policy and budget. This paper covers broad-brush EAPs that can assist employees with any type of personal or family problem (including, but by no means limited to, substance abuse), as opposed to programs that serve only a particular type of problem, such as alcoholism recovery.

The broad-brush approach is specially important for two reasons. First, it encourages referrals based on job performance only, and not a supervisor's unprofessional diagnosis of underlying causes. Second, it recognizes that personal problems can be manifold and that an individual's principal presenting problem may actually reflect other factors. (For example, it has been quite common for individuals to access the EAP for marital problems that are actually due to a spouse's alcohol or drug abuse.) Problems that are typically presented to the EAP, in addition to substance abuse, include marital and relationship problems, difficulties with children or aged relatives, financial and legal worries, emotional difficulties, compulsive gambling, disabling phobias, eating and weight disorders, and other personal and family crises.

An EAP can be implemented in-house or with an outside provider. In-house programs can be highly formalized, with full-time staff employed by the company, or informal, with interested employees simply acting as facilitators to direct coworkers to counseling and treatment resources within the community. Formal in-house programs are usually suitable only for the largest organizations, given the cost to employ staff, although they can be highly effective. Informal programs are effective only to the extent that individuals with problems are willing to confide in a fellow employee.

EAPs with an outside provider can range from using United Way agencies to service particular types of problems, to the formally contracted assessment and referral type of program implemented at Connecticut Transit. Another common arrangement is to use a preferred provider. In these cases, an outside counseling firm or treatment center assists a company's employees on a reduced fee-for-service basis, using the EAP as a client finder and, in turn, providing management with a professional referral for troubled employees.

REASONS FOR EAPs

Drug testing of transit workers and other initiatives to curb workplace substance abuse have undoubtedly spurred operators nationwide to implement or expand EAPs. Although they ultimately stepped back from requiring EAPs, even the 1988 UMTA regulations on drug testing (*2*) recognized that ". . . many organizations have found EAPs to be cost-effective elements of successful anti-drug programs."

The most obvious reason to have EAPs is simply that the cost of helping people solve personal and family problems is less than the cost those same problems, left untreated, extract from employers because of a poorer job performance. A widely accepted rule of thumb is that untreated problems in an average workforce cost the employer 2 to 3 percent of the total payroll just in terms of nonproductive time. According to one recent study, troubled employees are 16 times more likely to be absent from work, 2 times as likely to leave work early, 3 times as likely to arrive late, use one-third more sick leave and insurance benefits, have 4 times as many accidents, and file 5 times as many claims for worker's compensation than workers generally (*4*).

Moreover, the EAP plays a critical role in preventing employees' problems from becoming major crises in the workplace. Once a serious accident has occurred or an employee has reached the discharge step in an absenteeism policy, it is simply too late to find out that the underlying cause was a personal problem that could have been treated earlier. Again, in an average workforce, the generally accepted rule of thumb is that 1 out of every 10 employees has a personal or family problem serious enough to affect job performance. Similarly, a recent survey revealed that 88 percent of the chief executive officers of major U.S. corporations view drug abuse in society as a significant problem, and nearly one in four surveyed answered that drug abuse is a very significant problem within their companies (*5,6*).

Whether individuals are directed to the EAP by their supervisors or come voluntarily, EAPs can provide early intervention in resolving problems that, over time, can become increasingly debilitating. In this context, the broad-brush EAP approach is specially important. Except for the obvious and unique effect of chemical impairment on performance, all types of personal problems are manifested in similar ways on the job, such as absenteeism, distractions causing accidents and errors, and personality changes affecting relationships and attitudes. Obviously, substance abuse in the workplace involves special concerns about law violations, regulatory compliance, and the employer's public image. On the other hand, an inattentive employee is no more prone to causing accidents because he or she is wondering where to score drugs than if the distraction is because of worry about a marital crisis.

Having an EAP also helps to make credible a company's disciplinary policies—to employees, to the union, and to an arbitrator. Even when an employee is terminated for unsatisfactory performance, excessive absenteeism, or accidents on the job, arbitrators are loathe to uphold the discharge if the root cause is a personal problem that might be remedied by counseling and treatment. This concern is magnified in states where alcoholism and drug addiction are considered handicaps, giving added protection under antidiscrimination statutes to employees who might otherwise be discharged for misconduct. Having an EAP available ensures that individuals whose personal problems result in poor performance are performing poorly in spite of the employer's best efforts to offer help. Often, company policies specifically provide referral to the EAP as one option (or even as a formal step) in a process of progressive discipline.

At Connecticut Transit, the EAP is an integral element of policies regarding drugs and alcohol and off-duty arrest on drug- or alcohol-related charges. Although certain types of misconduct are considered automatic grounds for discharge (e.g., operating a revenue vehicle when alcohol intoxication is above the legal limit or selling an illegal drug on company premises), other circumstances can result in referral to the EAP in lieu of (or in addition to) normal discipline. The strong commitment to provide a low-cost, confidential source of help for employees' problems clearly has helped to make these necessary policies credible to employees and their union representatives.

According to a 1987 report by the American Public Transit Association (APTA) Task Force on Drug and Alcohol Abuse, EAPs are widely, but not yet universally, used by public transit operators. Although pioneer EAPs have existed for transit systems for more than a quarter-century, and although EAPs in some form were used by up to two-thirds of the respondents to an APTA survey, the Task Force nevertheless concluded (*7,8*) that "even today many transit properties do not have [EAPs] to deal with troubled employees." Reporting the results of a survey among Fortune 1,000 companies nationwide, Bradley Googins of Boston University (*5*) concluded:

> In most corporations with an EAP, there are still pockets of untrained supervisors, uninformed employees, and uncovered sites. Many EAPs exist on paper only. Others have barely scratched the surface of the alcohol and drug problem and are still on the periphery of the organization.

THE EXPERIENCE OF CONNECTICUT TRANSIT

Since the program began in 1987, nearly 200 individuals have used Connecticut Transit's EAP services. This annualized utilization rate of approximately 7.5 percent demonstrates that the program has been well received by employees and their family members. Normally, a utilization rate of 5 percent for an EAP is considered good.

Over time, the percentage of self-referrals has increased significantly to the point that company referrals due to job performance problems represent only about one-third of all EAP contacts. This is probably the best indicator that the program has been communicated effectively to employees as a genuinely credible, caring, and confidential source of help for problems outside the workplace.

Although substance abuse has historically been the most common problem of employees accessing the EAP, it represents the primary problem in less than half of all cases. Marital, family, and other relationship problems account for the next largest number of EAP contacts. These data confirm that the program has been successfully developed as a broad-brush resource for addressing any type of personal or family problem, and at least one recent study confirms the experience of Connecticut Transit as typical of many EAPs nationally (*9*).

About one-fourth of the cases were effectively resolved by the EAP without need for additional referral. A lesser number of cases were presented to the EAP in crisis, resulting in immediate referral for inpatient treatment. Over the past 3 years, nearly three-quarters of the cases closed indicated improvement or resolution of the problems originally presented.

ISSUES TO CONSIDER IN PLANNING AN EAP

The current EAP at Connecticut Transit evolved over several years. In effect, the success of the originally informal, no-cost approach demonstrated the need for a more formal, broadened, and enhanced program. In most communities, a variety of firms now offer EAP services. To select the program best suited to the needs of a particular workforce, several specific considerations should be weighed carefully (*10–12*).

EAPs like that at Connecticut Transit are usually contracted on the basis of an annual cost per employee. Cost, in turn, is mainly a function of three important variables:

- Services offered,
- Training and other management services, and
- Onsite services.

Services Offered

The EAP at Connecticut Transit is an assessment and referral model under which three initial counseling and assessment sessions are provided free of charge as part of the EAP contract. As indicated, many individuals are able to resolve their problems during these sessions. (Some EAP models provide up to eight initial sessions.) Employees who require longer term counseling or inpatient treatment are referred to other providers in the community. Some EAPs will provide long-term counseling directly at reduced, preferred provider rates. Other firms prefer to limit their services to assessment and referral only and will not refer clients to themselves. In planning an EAP, the extent of actual counseling services to be offered and the number of free sessions to be provided under the basic EAP contract will have the greatest impact on cost.

One concern about preferred provider arrangements is the almost inevitable conflict of interest that may arise because of the EAP's role as both referrer and referral. At Connecticut Transit, this problem has been avoided by using an assessment/referral EAP model. Significantly, however, the problem persists for some employees who have elected HMO coverage in lieu of conventional indemnity medical insurance. In many cases, HMOs are less willing to accept members' referral for costly inpatient treatment for chemical dependency. Instead, HMOs are more likely to encourage the sometimes inappropriate outpatient counseling that can be provided more inexpensively by the HMO's own staff.

Training and Other Management Services

Most EAPs emphasize supervisory training and employee orientation as integral elements of the program. An important consideration, therefore, is how much training will be provided and to whom. Supervisory training is usually focused on three areas: (a) familiarizing staff with the overall program, (b) increasing awareness of how employee problems affect job performance and overcoming enabling of undesirable behaviors, and (c) providing practical guidance on how to handle employee problems in the workplace and how to use the EAP as a management tool. Training is typically provided to all supervisory employees in 2- to 8-hr sessions with up to 25 participants. EAP providers can also conduct other types of specialized training workshops (e.g., stop smoking campaigns, employee wellness, and stress management seminars) at additional cost.

Finally, many EAP firms will assist in developing policies and procedures on a consulting basis with transit management. Many firms will also assist in publicizing EAP services to employees through methods such as brochures, posters, notices, paycheck stuffers, and orientation videos. These services may be highly desirable to employers who do not have formal drug and alcohol policies already in place.

Onsite Services

A third factor that greatly influences the cost of a contracted, broad-brush EAP is the extent of services to be provided at the employer's worksite. At Connecticut Transit, having the EAP keep office hours on the premises did not prove to be cost-effective. However, EAP representatives do perform periodic walk-throughs at each of the divisions, attend union meetings, and meet from time to time with managers and supervisors.

Two other considerations in planning an EAP are who should be covered and how employees will pay for long-term counseling or treatment services. The Connecticut Transit EAP specifically covers all employees and members of their immediate families. Many personal problems that affect job performance are actually family problems. The employee whose spouse is alcoholic may suffer attendance problems and distractions on the job no less than the employee who is himself or herself alcoholic. Likewise, when an employee's job performance suffers due to marital discord or difficulties with children, counseling for the entire family may be recommended. The principal focus of Connecticut Transit's current-year EAP campaign is specifically designed to increase the involvement of employees' families through direct mailings to their homes. Again, in our experience, family and relationship problems (including problems with children and aged relatives, marital difficulties, and family stresses due to health, legal, or financial problems) affect the majority of individuals who contact the EAP.

In designing an EAP, it is also important to review existing medical insurance coverages to determine what the employee's responsibility will be to pay a deductible and a percentage of counseling costs after the initial no-cost assessment period. The full cost of inpatient treatments for alcoholism or drug addiction is usually covered on the same basis as hospitalization for any illness. However, counseling and outpatient services are less likely to be covered in full by indemnity insurance or HMO plans. At Connecticut Transit, it was specially important to have the EAP work directly with employees' health insurance and HMO representatives in determining coverage for follow-up counseling services to preserve confidentiality.

THE ROLE OF THE UNION

Every employer has a different organizational culture regarding the union's role in establishing an EAP. In some companies, the EAP is a formally negotiated fringe benefit for which the union takes credit with employees and expects to play some direct, continuing role. Elsewhere, the EAP is established as part of a negotiated policy on alcohol and drug abuse, and thus is less likely to emphasize broad-brush services.

In general, unions were historically suspicious of EAPs for three reasons:

1. Unions were rightfully concerned that the confidentiality of employees who access the EAP voluntarily be protected,
2. Unions were concerned that EAPs were really a first step towards more stringent drug and alcohol policies and possible random testing of employees, and
3. Unions saw EAPs as encouraging employees to bring their workplace and personal problems to someone other than the union itself.

On the other hand, union leaders increasingly acknowledge their own concerns about drug and alcohol abuse in an industry that is historically held by law to maintain the highest standards of public and employee safety. In many cases, the availability of EAP services makes possible the rehabilitation of a troubled employee before deteriorating job performance triggers discipline and the cost of prosecuting a grievance arbitration. Not surprisingly, the Amalgamated Transit Union's model agreement on drug testing specifically requires the establishment of EAP services for all employees.

At Connecticut Transit, the EAP has been effectively characterized as an employee-sponsored program that has the support of both the union and management. A company-wide EAP steering committee, with representatives from local EAP committees in each division, coordinates the overall program. This approach is strongly recommended to help make EAPs credible to employees and their union. In turn, it has been very beneficial to have an EAP in place at Connecticut Transit before strengthening the company's rules and procedures for controlling drug and alcohol abuse.

The EAP steering committee at Connecticut Transit has also proven to be highly effective in keeping the EAP separated from both the union and management. Committee members have clearly embraced their roles as representing the interests of those employees who benefit from EAP services while recognizing that the EAP necessarily exists within the context of company policies and procedures, state statutes, and federal regulations.

SELECTING AN EAP PROVIDER

National concern for controlling workplace substance abuse has accelerated the proliferation of prospective EAP providers. One firm has franchised over 40 centers in nine states. Many hospitals, HMOs, treatment centers, and group counseling practices have expanded to offer EAP-type services. In fact, EAPs are typically unregulated, and almost any firm can declare itself to be an EAP provider. One of the principal professional membership organizations for EAP practitioners, the Employee Assistance Society of North America, has only recently adopted draft standards for EAP accreditation, and even these voluntary standards will not become effective until mid-1990 (*9,13,14*).

Unfortunately, the marketplace has spawned a number of firms representing themselves to be EAP specialists who are actually more experienced in management consulting and the sale of training aids, with counseling services provided only on an incidental basis by subcontractors. Selecting an EAP firm thus requires great care. By involving employees (and, as necessary, the union) in the selection, both the process and the selected EAP contractor are made more credible.

On the basis of experience at Connecticut Transit, the following key issues should be considered in evaluating proposals from prospective EAP firms:

- Corporate references,
- Staff resumes,
- Referrals,
- Flexibility of training,
- Follow-up, and
- Emergency services.

Corporate References

Checking corporate references is by far the most important step, although it is also the easiest to overlook. Ask each prospective firm to submit the names and telephone numbers of people to contact for specific information about their work for other employers. Check all references, specially those for major corporations in your community. Instances occurred in Connecticut in which large employers were listed as clients when, in fact, they had worked with the EAP only on an incidental basis several years earlier. Ask specifically for a description of the EAP services provided, utilization statistics, the nature and extent of staff training provided under the EAP contract, cost, and other comments about the contractor's performance. EAP services are necessarily highly personalized. It is therefore essential to speak with references who have first-hand experience with the prospective EAP firm and also with the individual counselors and EAP contract manager that are being proposed for your company.

Staff Resumes

Just as important as the corporate references of an EAP are the individual qualifications of its staff who will serve your employees. Ask each prospective firm to submit curricula vitae for the staff who will actually be involved in counseling your employees, not just for the firm's principals. This is also a useful technique to identify firms that intend primarily to farm out clinical assessment and counseling to subcontractors. A sound general policy is to choose an EAP firm based on its clinicians, not its salesmen or its chief executive.

However, because many good firms do subcontract with individual practitioners, it is important to establish how counselors are selected and to review their credentials as part of the selection process. Note the counselors' professional affiliations and whether they have current clinical certifications. Also note the breadth of actual counseling experience in such areas as inpatient chemical dependency treatment, outpatient counseling, family therapy, and work with children and adolescents. Some practitioners bring a broad background of clinical experience to the EAP, whereas others may simply be attempting to supplement a private practice that specializes, for example, in marriage counseling.

Referrals

Ask prospective firms to list the treatment centers and other community resources to whom they normally refer patients with different types of problems. This is an especially important consideration if, as was the case at Connecticut Transit, an employer already has good working relationships with particular inpatient treatment centers. Also ask prospective firms how they would handle special referrals—for example, a non-English-speaking employee or an individual who has minimal financial resources to pay for outpatient counseling.

Flexibility of Training

How flexible is the EAP provider to customize supervisory training, employee orientation, and other programs within the cost of your basic EAP contract? To what extent will the firm tailor its programs to meet particular client needs? Some firms use essentially the same canned program for all employers and charge extra for adaptations. Others will work closely with each client to identify needs and prepare specialized training needs.

This concern also applies to the publicizing of EAP services and orientation of employees. At Connecticut Transit, it has been extremely helpful to have EAP representatives attend union meetings and make periodic walk-throughs at each of our facilities. EAP counselors have ridden buses and visited the maintenance shops to experience first hand the work environment of our employees.

Follow-Up

Once an employee has been referred for counseling or inpatient treatment, what follow-up is provided by the EAP firm? In many respects, aftercare monitoring is as important as the initial treatment. Thus, in selecting the provider for Connecticut Transit, the commitment to follow up within the overall contract was considered an important criterion.

Emergency Services

Most EAPs provide a 24-hr telephone number for employees and family members to call. However, at least during off-hours, this number is usually only an answering service that will forward messages to a counselor. An important consideration is how quickly the EAP can respond in an emergency, such as when an employee is in the supervisor's office and needs to be evaluated for treatment immediately. Although few EAPs will ever admit that their services might be unavailable in an emergency, it is important during the evaluation and selection process to be ensured of the firm's commitment to provide whatever help is needed at any hour of the day or night.

FUTURE ISSUES

As discussed, the advent of drug testing for safety-sensitive employees has been an impetus for transit systems to establish EAPs. At the same time, however, the evolving context in which transit systems expect EAPs to function has created tensions that challenge the basic relationships between EAPs, the employers who pay contract costs, and employees who use EAP services. Three concerns in particular warrant special attention.

Fitness for Duty Evaluations

In general, EAPs will neither perform, nor attempt to substitute for, functions that should properly be performed only by a medical doctor. In particular, these include collecting urine or blood samples for testing, determining whether an individual is or was physically impaired on the job, and, most sensitive of all, determining whether an individual is fit to return to duty following medical treatment.

In the case of employees who are specifically recommended for inpatient treatment and detoxification for alcohol or drug addiction, the treating physicians normally make the required determination of an employee's fitness for duty. In many cases, however, the problems employees bring to the EAP are nonmedical. EAPs usually request (and, in the case of supervisory referral, employers usually require) employees to sign a waiver that allows the EAP to communicate specific information back to the employer, such as whether the employee completed a recommended treatment. Again, however, it tests the limits of an EAP's legal and ethical bounds to expect its staff to state definitively that an employee is fit or not fit to work. Such a role also impinges on the critical three-way relationship between EAPs, employers, and employees. There is at least a potential conflict of interest if the pronouncement of an individual's fitness or nonfitness for duty becomes a matter of contention between the parties (not to mention an issue of legal liability).

Once the medical review officer or other medical authority has made a fitness-for-duty determination, the EAP can play an important role in assisting employees' reintegration to the workplace and monitoring follow-up services. The EAP may also be called upon to periodically reassess employees who have returned to work following treatment for substance abuse or other problems.

Rehabilitating Employees

Company drug and alcohol policies often provide referral to the EAP in lieu of (or in combination with) progressive discipline for misconduct that does not warrant immediate discharge. For example, under various circumstances, the policy at Connecticut Transit would allow management to refer to the EAP for evaluation and referral an employee who tested positive for a controlled substance. Certainly, unions have argued that all employees who test positive for drugs should be given at least one opportunity for rehabilitation through the EAP before their employment is terminated.

The notion that EAPs can perform a rehabilitative function in every instance of employee misconduct or substance abuse not only is doubtful, but potentially undermines both the purpose of the EAP and the normal disciplinary process of the employer. Indeed, the more often that referrals to the EAP are based on any criteria other than the employee's overall job performance, the less likely it is that the EAP can perform an appropriate rehabilitative role.

The experience at Connecticut Transit and elsewhere indicates that the root causes of an employee's measurable, deteriorating job performance can be substantially addressed, and often ameliorated, by intervention of the EAP. However, when EAP referral is triggered by a single act of misconduct (e.g., an employee caught smoking marijuana or drinking beer on a lunch break), or worse, where referral is triggered solely by the positive result of a random urinalysis test, rehabilitation through the EAP may not be appropriate.

Proponents of extending rehabilitation services in all cases argue that alcoholism and drug addiction are illnesses that warrant treatment, not discipline. Yet many people who use alcohol and drugs are not chemically dependent. As the screening process becomes more random and indiscriminate, the likelihood increases that employees who test positive will not be addicts or alcoholics, but simply irresponsible individuals. Just as EAP referral is not necessarily appropriate in every instance of employee misconduct, neither does the EAP necessarily have a rehabilitative role to play for every employee whose urine test is positive.

However, EAPs do play a vital role in assessing the nature of individuals' underlying problems, the appropriateness of further counseling or treatment, and the individual's receptivity to accept intervention. As such, referral to the EAP may still be warranted in every instance where employees' urinalysis tests are positive, although the EAP's assessment in individual cases may be that rehabilitative counseling and treatment are unwarranted.

The EAP as Discipline

The preceding sections of this paper have referred frequently to the use of EAPs in conjunction with progressive discipline. However, it is vital that referral to the EAP not be perceived either by employees or supervisors as a form of punishment (comparable, perhaps, to a student's being sent to the principal's office for misbehaving in school).

Rehabilitation through any EAP demands the employee's full cooperation. Vigorous denial that a problem even exists is typical behavior of chemically dependent individuals, and most people are naturally reluctant to discuss personal affairs or admit that they cannot control personal problems. As such, gaining employees' trust, overcoming denial, and confronting unpleasant realities constructively are primary objectives of an EAP counselor. This already delicate relationship is undermined to the extent that employees see their referral to the EAP as a form of punishment, rather than a caring and constructive alternative to conventional discipline. In many instances, this subtle distinction is conveyed by the supervisor's manner and choice of words at the time of an employee's referral—hence the strong emphasis on supervisory training that is integral to most EAPs.

Similarly, overly identifying the EAP with drug testing undermines its other broad-brush functions. At Connecticut Transit, special efforts have been made to clarify this role and to ensure that different individuals are involved in the general counseling and referral of troubled employees and the specific assessment of employees who fail a urinalysis drug test.

CONCLUSIONS

Although the widespread national concern over workplace substance abuse has accelerated the implementation of EAPs, special care must be exercised to ensure that local programs are effectively tailored to the individual needs of each employer and workforce. EAPs can play a vital role as part of company policies to prohibit alcohol and drugs from the workplace, but their limitations must also be recognized. EAPs should not supplant the role of a company physician to make individual determinations of fitness for duty; rehabilitation through the EAP is not necessarily appropriate in every instance of employee misconduct; and integrating EAPs with disciplinary policies risks the perception that referral to the EAP is a form of punishment.

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Accuracy in Transit Drug Testing: A Probabilistic Analysis

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The accuracy of drug tests for transit and other transportation workers is an important subject. Concepts of accuracy that are most relevant are applied to laboratory proficiency and transportation worker drug-usage data, and accuracy levels that could occur in transit drug testing programs are estimated. Seemingly accurate tests for abused drugs can sometimes be inaccurate to a disturbingly high degree. Therefore, a methodology by which decision makers can correctly set desired accuracy standards for their organizations is suggested to avoid potential inaccuracies.

Substance abuse by transportation workers has become a major concern to public officials, transportation agencies, and unions. As a result, there has been a rapid increase in the testing of workers for the presence of illegal substances. Recent federal requirements for the testing of transportation employees has accelerated the trend (*1*–*5*).

The use of drug tests is based on the premise that they correctly identify both the presence and the absence of certain drugs. If the tests do not identify most drug users, then they are not an effective method for apprehending abusers or encouraging abstinence. Even worse, if nonusers test positive for drugs, they may be marked for life for an offense they did not commit. Our legal system, as well as our system of workplace jurisprudence, requires that a person be assumed innocent until proven guilty with compelling evidence. Thus, drug testing should be used only when the tests can correctly categorize users and nonusers, with the categorization of nonusers being especially important.

The U.S. Department of Transportation (DOT) has recognized the crucial importance of correct test results and requires that rigorous accuracy standards be met by drug testing laboratories, with special emphasis on false positive errors. A laboratory's certification is subject to review and revocation unless the accuracy requirements are met (*4*).

The accuracy of drug tests for transit and other transportation workers is therefore an important subject. In the following sections, concepts of accuracy that are most relevant are reviewed and applied to laboratory proficiency and transportation drug use data, and accuracy levels that could occur in transit drug testing programs are estimated. Seemingly accurate tests for abused drugs may sometimes be inaccurate to a disturbingly high degree. Therefore, a methodology is suggested by which decision makers can correctly set desired accuracy standards for their organizations, in order to avoid potential inaccuracies.

TERMINOLOGY

To clarify the terminology and concepts used in this paper, the following discussion is offered. Excellent discussions from somewhat differing viewpoints may be found in *Quality Assurance in Drug-Use Testing* (*6*) and *Drug Testing in the Workplace* (*7*).

When a specimen is tested for drugs, one of four outcomes must occur:

- True positive—specimen with drugs tests positive for drugs,
- True negative—specimen with no drugs tests negative for drugs,
- False positive—specimen with no drugs tests positive for drugs, or
- False negative—specimen with drugs tests negative for drugs.

Given that a specimen contains drugs, it must test either (true) positive or (false) negative. That is, the probability of a positive test result (given drugs are present) plus the probability of a negative test result (given drugs are present) must equal 1.0. This equation may be written

$$P(+|\text{drugs}) + P(-|\text{drugs}) = 1.0 \qquad (1)$$

In other words, when drugs are present in a specimen, the probabilities of a true positive and a false negative must total 1.0.

Similarly, a specimen without drugs must test either (false) positive or (true) negative. This equation may be written

$$P(+|\text{no drugs}) + P(-|\text{no drugs}) = 1.0 \qquad (2)$$

Thus, the probability of a positive test result (given no drugs are present) plus the probability of a negative test result (given no drugs are present) equals 1.0.

Three measures of drug test accuracy are used in the health-related professions: sensitivity, specificity, and predictive value. Sensitivity is the probability that a specimen with drugs will test positive. Thus, it equals the probability of a true positive, i.e.,

$$\text{Sensitivity} = P(+|\text{drugs}) \qquad (3)$$

A second concept used in evaluating the accuracy of laboratory tests is specificity. Specificity is the probability that a drug-free specimen will test negative, i.e., the probability of a true negative.

$$\text{Specificity} = P(-|\text{no drugs}) \qquad (4)$$

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Thus, sensitivity measures the ability of the test to correctly report the presence of drugs, whereas specificity measures the ability of the test to correctly report the absence of drugs. For an ideal test, sensitivity and specificity would both be equal to 1.0, meaning that every drugged specimen tests positive and every nondrugged specimen tests negative.

In drug testing, the most important concern is incorrect results, that is, occurrence of false positives and false negatives. Sensitivity and specificity are indirect indicators of the false result rates. $P(+|\text{no drugs})$, the probability of obtaining a false positive, is equal to $(1 - \text{specificity})$. $P(-|\text{drugs})$, the probability of obtaining a false negative, is equal to $(1 - \text{sensitivity})$. Thus, the higher the sensitivity, the lower the false negative rate. The higher the specificity, the lower the false positive rate. What laboratories should do, therefore, is maximize sensitivity and specificity, because this will minimize the false negative and false positive rates.

An important concept, although not widely used in studies measuring laboratory proficiency, is the positive predictive value (PPV) of a test. For drug tests, the PPV is the probability that the drug is present in a specimen, given that the test yielded a positive result. That is,

$$\text{PPV} = P(\text{drugs}|+) \tag{5}$$

For example, if 90 out of every 100 people testing positive for drugs have truly taken drugs, then the PPV of the test is 0.90. The probability that a person with a positive test result truly has not taken drugs is 0.10. That is, if a drug test has a PPV of X, then the probability is $(1 - X)$ that a person testing positive is drug free.

Thus, maximizing the PPV of a test also minimizes the probability that specimens testing positive are truly drug free. The latter probability is the false conviction rate. That is,

$$\text{False conviction rate} = P(\text{no drugs}|+) = 1 - \text{PPV} \tag{6}$$

This concept is important in determining whether a positive result on a drug test provides sufficient evidence of drug usage. If, for example, positive results on a test are known to be untrue in 1 out of every 10 cases, i.e., the false conviction rate = 0.1, then a positive test would not be considered sufficient evidence to convict a person of drug use. More important, in protecting the innocent from false accusation the PPV (or, equivalently, the false conviction rate) of the test is of prime concern.

Specificity, sensitivity, and predictive value may be stated as either probabilities or percentages (*6–8*). Both are used here, as the context dictates.

DRUG ABUSE BY TRANSPORTATION WORKERS

Not surprisingly, estimates of drug usage vary widely. Because using drugs of abuse is usually illegal but often considered to be in style, self-reports may not be very reliable. Similarly, those making pronouncements about the extent of drug abuse often have strong incentives for claiming that drug usage is either very high or very low. Finally, the characteristics of the group about which the estimates are made can cause wide variations, because drug usage varies on the basis of age, geographic location, and other variables. Considering these caveats, several estimates of the extent of drug abuse are provided.

In late 1989, the National Institute on Drug Abuse (NIDA) estimated, on the basis of self reports, that 7.1 percent of all Americans over 18 used some illegal substance at least once during the month before their 1988 household survey, although usage dropped to 2.1 percent for people over 35 years old (*9,10*).

A 1989 U.S. Department of Labor report (*11*) based its estimates on the results of employer drug tests. For all of the industries surveyed in 1988, 8.8 percent of the employees tested positive, with the workforces of the smallest firms tending to have the lowest positive rates. For the transportation industry, 5.6 percent of the employees tested positive. (Rates in other industries ranged from 20.2 percent in wholesale trades to 3.1 percent in services; transportation's rate was the second lowest of the industries reported.)

In 1986 and 1987, tests of railroad workers involved in train accidents revealed that 29 of 759 people, or 3.8 percent, tested positive for drugs of abuse (*12*).

Estimates are also available for one of the nation's larger transit properties. In 1988, 2.74 percent of its employees tested for drugs tested positive, as did 2.58 percent of those tested in early 1989 (*13*).

These last three estimates were based not on random drug tests primarily, but on tests often administered to employees under conditions where one would expect drug usage to be higher than usual. Thus, they may overestimate the extent of drug usage for the three workforce groups involved.

In a final estimate, DOT randomly tested more than 16,000 of its own employees between July 1, 1988, and June 30, 1989. Of these, 99 tested positive, for a rate of 0.619 percent (*14*).

On the basis of these estimates, transit employee drug usage may be in the range of 0.6 to 5.6 percent. Typically, transit systems in the larger cities and with younger workers would have higher rates, whereas systems in smaller towns and with older workforces would have lower ones. Allowing that some systems will have higher or lower rates, for the nation as a whole the transit average is probably in the 0.6- to 5.6-percent range. Consequently, rates from this range are used in the analyses in this paper. (When this statistical methodology is used for a specific system, then the estimated drug abuse rate for that particular system should be used.)

ACCURACY OF DRUG TESTING

A topic no less subject to disagreement than the proportion of workers using drugs is the accuracy of the tests for such substances. Here also, estimates of accuracy often seem to be based more on the self-interests of the claimants than on sound empirical evidence. Additionally, a variety of factors, such as characteristics of the laboratories involved, the testing methods used, the testing protocols actually followed, whether proficiency tests are open or blind, concentrations of the drugs in spiked challenges, and other influences can cause large variations in accuracy.

Because of the concerns over whether this testing correctly identifies the presence or absence of drugs, a number of laboratory proficiency studies have been conducted. In these studies, prepared samples are sent to laboratories to determine the accuracy of their testing procedures.

Rather than review all laboratory proficiency studies, estimates from two recent articles published in the *Journal of the American Medical Association* (JAMA) will be used (*15,16*). The studies on which these articles were based appear to be the most relevant to transit to date. Before examining the empirical results reported in the two JAMA articles, however, two other examples recently reported in transportation literature (*17*) will be briefly discussed, to explain why they are not used herein. One is a study conducted by the American Association of Clinical Chemistry (AACC) (*18*), and the other is the experience of the U.S. Navy.

The AACC study (*18*) was conducted explicitly to show how accurate AACC-member laboratories could be, rather than from a neutral viewpoint. The drug concentrations in the spiked positive challenges were quite high, and it was not a blind study. Because it was an open study, the laboratories knew precisely which specimens were being used for the test. Because of the high concentrations for most types of drugs tested, the challenges were easier to detect and were unambiguously positive or negative. Therefore, the AACC findings are probably not representative of how laboratories would perform under routine testing conditions, although they do represent the results attainable with current technology and ideal conditions. Thus, Davis et al. concluded about the AACC study (*16*, p. 1753): "It is clear that at sufficiently high drug concentrations, a selected group of laboratories can perform well in an open proficiency testing format."

For the Navy case, it was reported in the transportation literature (*17*, p. 26) that "the U.S. Navy submitted 6,000 blind quality control samples to testing laboratories without a single false positive result." No dates on when these results occurred were provided. However, another source reports that in 1982 the Navy reexamined 6,000 positive samples to assess the accuracy of the test results. Of the 6,000, 2,000 could not be "scientifically substantiated as positive," and some documentation was missing on 2,000 more (*19*, p. 48).

Another discussion of military testing, written in 1988, concludes (*2*, p. 54): "Although [tests by the military] have been sharply improved, the military examples illustrate how grossly test results can be in error, even with the most accurate analytic techniques, where quality control measures are lax, and how otherwise small error rates can increase as the number of tests increase." Neither the AACC study nor the Navy experience is representative of the accuracy that transportation organizations can expect for routine testing from civilian laboratories, but the two laboratory proficiency studies reported in JAMA should be examined.

The 1985 JAMA study (*15*) reported the results of blind and open proficiency tests for various drugs of abuse conducted in 1981 by the Centers for Disease Control in conjunction with NIDA. The 1988 study (*16*) reported the blind and open proficiency tests of laboratories conducted by NIDA in 1986 and 1987. Both studies used samples of civilian labs with experience in testing for abused drugs.

Not all of these laboratories used gas chromatography/mass spectrometry (GC/MS) for confirmation testing of specimens screening positive, and the laboratories in the 1985 study may not all have performed confirmation tests. However, it appears that the laboratories in the 1988 JAMA study (*16*) did conduct confirmation testing of specimens that initially screened positive, and the most frequently used confirmation method was GC/MS.

More specifically, the 1985 study (*15*) did not report whether its laboratories conducted confirmation tests on specimens reported positive by the initial screening test. The 1988 study said that during the open phase, specimens screening positive were subjected to confirmation testing. The most frequently used confirmation method was GC/MS. GC/MS was always used for confirmations by about half of the laboratories and sometimes used for confirmations by about another one-sixth. The remaining confirmations used either high-performance thin-layer chromatography or high-performance liquid chromatography. The authors of the 1988 article (*16*) were uncertain whether confirmations took place for all specimens screening positive in the blind portion of the study. However, there is evidence to suggest that such confirmations did occur. The false positive rates for the open and blind phases were almost identical, each rounding to a rate of 0.002 (the rate during the open phase being slightly higher). Because the false positive rates were virtually the same for both the open and blind phases, it is likely that the same confirmation procedures were used for each. Because it is certain that confirmations took place during the open phase, when the laboratories knew precisely which specimens were being used for the test, the rate of 0.002 appears to be the applicable false positive rate when confirmation is required.

GC/MS is generally considered to be the confirmation method that can theoretically produce the most accurate results. However, the fact that it was not used in every case in the 1988 JAMA blind study (*16*) does not necessarily mean that the resulting specificity estimates were lower (or, equivalently, that the false positive rates were higher) than they would have been if GC/MS had been the sole confirmation method used. GC/MS requires a higher level of skill and care than some of the other methods. These requirements may not always be met in the routine testing that blind proficiency studies attempt to duplicate, so the theoretical advantage of GC/MS may be lost. Although confirmation with GC/MS theoretically makes misidentification less likely, mistakes are possible (*7*). In short, no empirical evidence proves that blind proficiency studies of laboratories using only GC/MS for confirmations would yield higher specificity (that is, lower false positive rates) than did the laboratories in the 1988 JAMA study (*16*).

Moreover, there have been no independently conducted blind proficiency studies of the performance of laboratories certified by NIDA under actual transit agency testing conditions. When such data are available and applicable, the resulting sensitivity and specificity rates should be used. The mere fact that UMTA-required standards might in theory result in more accurate tests is not sufficient to prove that they do so in practice. The Navy also had high standards, yet there was substantial inaccuracy, because the standards were not initially enforced adequately in practice (*2,19*). Instances of high theoretical standards and lax enforcement in transportation drug testing have already occurred (*14,20,21*).

Because it seems that the two JAMA articles (*15,16*) contain the most relevant published averages to date, they are used here for illustrative purposes. The 1988 article (*16*) is more representative of recent experience than the 1985 article

(*15*), and it is closer to what can be expected of NIDA-certified laboratories. However, many laboratories today are similar to those reported on in the 1985 study, and there may be laboratories that are even less accurate (*22*).

If the accuracy of a laboratory used by a particular transit agency is claimed to be higher or lower than those in the JAMA studies, the burden of proof should be on the claimant to provide supporting empirical evidence. That is, because laboratories differ in their sensitivity and specificity rates, individual transit properties should obtain blind study estimates for the laboratories they use in order to estimate the true accuracy of their own results. This should be done whether or not theoretically uniform transit standards exist.

Based on calculations from data presented for the blind phases of the JAMA proficiency studies, the false positive rate (false positives/negative challenges) was 0.014 in the 1985 article (*15*) and 0.002 in the 1988 article (*16*), representing findings on the proportions of drugless samples where drugs were incorrectly reported to be present. (A negative challenge is a specimen that does not contain a drug being tested for by the study.) These statistics are, of course, estimates of $P(+|\text{no drugs})$ and are equivalent to specificity levels of 98.6 and 99.8 percent, respectively.

The authors of the 1988 article (*16*) calculated the false positive rates by a different method, thus reporting false positive rates of 0.013 for the blind phase and 0.016 for the open phase of their study, as compared to the blind and open rates of 0.0018 and 0.0019 calculated here. The false positive rates reported in the 1988 study (*16*) are about 10 times higher than those resulting from these calculations.

The false negative rates (false negatives/positive challenges) were 0.618 in the 1985 study (*15*) and 0.311 in the 1988 study (*16*). These statistics estimate the value of $P(-|\text{drugs})$ and reflect sensitivity levels of 38.2 and 68.9 percent, respectively. (A positive challenge is a specimen that does contain a drug being tested for by the study.)

The results of open tests, those involving urine samples that laboratories knew were being used for quality checks, are not used herein. Results of blind tests, those in which the laboratories did not know they were being tested, are much more representative of what one could typically expect when actual urine samples are submitted. Therefore, only blind test results were used for the research presented here.

BAYESIAN ANALYSIS

Most employers do not want to accuse workers of drug usage if there is reasonable doubt about their guilt. However, if 99 percent of drug-free employees test negative, then many employers would conclude that reasonable doubt does not exist when an employee tests positive. Because the percentages of the drug-free specimens testing negative in the JAMA studies were 98.6 and 99.8 percent, it would appear that drug tests are accurate enough that reasonable doubt could not be established.

However, the results are not what they seem, as Bayesian analysis of AIDS test and drug test results have exhibited (*23–25*). The first case is described in Table 1.

As shown for Case 1 in Columns 2 and 3 of the table, a urine specimen must either contain drugs (S_1) or contain no drugs (S_2). For this case, it is further assumed that the probability is 0.056 that the urine specimens truly contain drugs, requiring that the probability is 0.944 that they do not, as shown in Column 4. These probabilities imply that 5.6 percent of the target population uses drugs; recall that this is the rate estimated for all transportation workers in the U.S. Department of Labor survey. The next column, Column 5, identifies the probability of the urine specimen's testing positive for drugs when there truly are drugs present (0.382), and when there truly are no drugs in the sample (0.014). That is, $P(+|\text{no drugs}) = 0.014$, and $P(+|\text{drugs}) = 0.382$. These probabilities are taken from the 1985 JAMA study (*15*).

The numbers in Column 6 are the products of the numbers in the two previous columns. That is, for the population being tested, the probability that a person truly is on drugs and tests positive for drugs is 0.021392, whereas the probability that a person truly is not on drugs and tests positive for drugs is 0.013216. The sum of these two probabilities, denoted by $P(+)$ and equal to 0.034608, is the probability of a positive test result.

Dividing each of the numbers in Column 6 by $P(+)$ yields the numbers in Column 7, which are the probabilities of being in the particular states, given a positive test result. Thus, the probability that specimens that test positive will contain drugs is 0.618, meaning the test has a PPV of 61.8 percent. The probability that specimens testing positive will truly contain no drugs is 0.382, meaning the test has a false conviction rate of 38.2 percent. That is, $P(\text{drugs}|+) = 0.618$, and $P(\text{no drugs}|+) = 0.382$, with the two probabilities totaling 1.

These same results can be developed more intuitively by considering a group of 1,000 workers who are tested for drug usage. If 5.6 percent of the group are truly taking drugs, then 56 workers will provide urine specimens that contain drugs, and the remaining 944 will provide specimens that are drug free. Of the specimens containing drugs, $56 \cdot 0.382 = 21$ will test positive for drugs, and the remaining 35 will test negative. Similarly, of the specimens not containing drugs, $944 \cdot 0.014 = 13$ will test positive for drugs, and the remaining 931 will test negative. Thus, $21 + 13 = 34$ specimens will test positive for drug usage, although 13 of these 34 do not actually contain drugs. That is, 13/34 (or 38.2 percent) of those testing positive for drug usage will truly be drug free.

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

Of course, the actual probability that a person who tests positive is not on drugs will differ under different assumptions about (a) the percentage of the target population that is actually taking drugs, (b) test specificity, and (c) test sensitivity. Different assumptions are presented in Cases 2 through 8.

In Cases 2 through 4, the estimates of the proportion of the target population on drugs were varied. Whereas Case 1 used the rate (0.056) estimated for all transportation workers, Case 2 used the rate (0.038) estimated for railroad workers

TABLE 1 APPLICATION OF BAYESIAN ANALYSIS TO TRANSPORTATION DATA

[1] CASE	[2] STATE	[3] S_j	[4] $P(S_j)$	[5] $P(+\|S_j)$	[6] $P(+\|S_j)P(S_j)$	[7] $P(S_j\|+)$
1	Drugs	S_1	0.056	0.382	0.021392	0.618
	No Drugs	S_2	0.944	0.014	0.013216	0.382
	Total		1.000		P(+)=0.034608	1.000
2	Drugs	S_1	0.038	0.382	0.014516	0.519
	No Drugs	S_2	0.962	0.014	0.013468	0.481
	Total		1.000		P(+)=0.027984	1.000
3	Drugs	S_1	0.026	0.382	0.009932	0.421
	No Drugs	S_2	0.974	0.014	0.013636	0.579
	Total		1.000		P(+)=0.023568	1.000
4	Drugs	S_1	0.006	0.382	0.002292	0.141
	No Drugs	S_2	0.994	0.014	0.013916	0.859
	Total		1.000		P(+)=0.016208	1.000
5	Drugs	S_1	0.056	0.689	0.038584	0.953
	No Drugs	S_2	0.944	0.002	0.001888	0.047
	Total		1.000		P(+)=0.040472	1.000
6	Drugs	S_1	0.038	0.689	0.026182	0.932
	No Drugs	S_2	0.962	0.002	0.001924	0.068
	Total		1.000		P(+)=0.028106	1.000
7	Drugs	S_1	0.026	0.689	0.017914	0.902
	No Drugs	S_2	0.974	0.002	0.001948	0.098
	Total		1.000		P(+)=0.019862	1.000
8	Drugs	S_1	0.006	0.689	0.004134	0.675
	No Drugs	S_2	0.994	0.002	0.001988	0.325
	Total		1.000		P(+)=0.006122	1.000

involved in accidents, Case 3 used the most recent rate (0.026) found at the large urban transit system, and Case 4 used the rate (0.006) found as a result of the random tests of its workers by DOT. This variation in assumed rate provides an indication of the sensitivity of the final outcome to changes in the rate of drug usage in the target population.

In Cases 5 through 8, the same four rates of drug usage were repeated, but the 1988 JAMA article (*16*) estimates of sensitivity and specificity were substituted. These estimates were 68.9 and 99.8 percent (which represent a false negative rate of 0.311 and a false positive rate of 0.002, respectively).

Thus, for Cases 1 through 4, about two out of every five positives will represent those who have not taken drugs when all transportation workers are considered, one out of every two positives will represent drugless employees for railroad workers in accidents, three out of every five positives will represent drugless employees for workers at the large transit system, and six out of every seven positives will represent drugless employees for the population of transportation employees being tested by DOT. In other words, for these four cases the false conviction rates are 38, 48, 58, and 86 percent, respectively. Under any of these circumstances, such test results have no value in proving drug use.

The error rates are lower for Cases 5 through 8, where sensitivity and specificity rates were drawn from the 1988 JAMA article (*16*). In these four scenarios, approximately 1 out of every 20 transportation employees who tested positive would be falsely accused, as would approximately 1 out of every 15 railroad employees, 1 out of every 10 of the large transit system employees, and 1 out of every 3 DOT employees. These represent false conviction rates of 5, 7, 10, and 33 percent, respectively. Although these results are better than those for the first four cases, it seems that convicting even 5 percent falsely, with such serious consequences, is an extremely high error rate.

Very importantly, these false conviction rates are based on our estimated average rates for drug usage, sensitivity, and specificity and are not necessarily applicable to any particular transit agency. But all of our estimated rates are ones that could occur in some circumstances. Because of the extremely serious consequences of being convicted of drug use, an employer would be wise to determine that these estimated rates, or similar rates, do not apply before acting on positive drug test results.

The situation would be improved if sensitivity and specificity levels could be increased. Another alternative is to test only those groups with high rates of drug use, and to test only in those situations where sufficient accuracy can be obtained. One way to do this is examined next.

METHODOLOGY FOR DEVELOPING ACCEPTABLE PREDICTIVE PROBABILITIES

Once a decision maker has estimated the percentage of the target population taking drugs and has determined the acceptable percentage of those testing positive but not on drugs, that is $P(\text{no drugs}|+)$, then he or she can identify various combinations of specificity and sensitivity rates that will yield the acceptable percentage of those testing positive but not on drugs. Then, by conducting blind tests of the laboratories being used, it would be possible to determine whether the sensitivity and specificity requirements are actually being met. This methodology is discussed in this section.

First, assume that out of every 100 samples that test positive for drugs, a maximum of 1 should be truly drug free, $P(\text{no drugs}|+) \leq 0.01$. That is, the minimum PPV of the test would be 99 percent. These standards require that out of every 100 workers testing positive for drug usage, at least 99 of them will indeed have drugs in their systems, but 1 at the most will not. Thus, the false conviction rate will be no more than 1 employee out of every 100 testing positive, or 1 percent, because the ratio (drug users)/(positive test results) $\geq$ 99/100.

Some might argue that this probability is too high, and others may feel that it is too low. Whatever level is chosen could be determined by collective bargaining in unionized situations, unilaterally by top decision makers, or perhaps set by DOT decree. However, it is the PPV, not the sensitivity or specificity rates, that must be set correctly. Any PPV desired could be substituted for the one used here.

Second, it is necessary to estimate the proportion of the target population that is using drugs. For purposes of this example, 3.0 percent of the employees are assumed to have drugs in their systems. This parameter is slightly above the usage rate found at the large transit agency described earlier, but it could be replaced by any appropriate percentage.

Once the drug usage rate and the desired PPV have been established, it is possible to calculate the combinations of sensitivity and specificity levels that will be acceptable. For this example, it is estimated that $P(\text{drugs}) = 0.03$, and it is required that $P(\text{no drugs}|+) \leq 0.01$. Using these values in the appropriate Bayesian formula and simplifying yields

$$P(-|\text{no drugs}) = 1 - [0.0003124 \cdot P(+|\text{drugs})] \quad (7)$$

Now, the different combinations of specificity $P(-|\text{no drugs})$ and sensitivity $P(+|\text{drugs})$ that satisfy the equation can be calculated.

As the formula indicates, the lower the sensitivity, the higher must be the specificity. The acceptable sensitivity and specificity combinations are shown in Figure 1. Any combination on the line will exactly satisfy the requirements, any combination above the line will more than satisfy them, and any combination below the line (in the shaded area) will not satisfy them.

When the sensitivity in Figure 1 is zero, meaning none of the true drug users are identified, the required specificity is at its highest level, 1.00 (i.e., 100 percent). That is, if the probability of a false negative given drug usage is 1.00, then there will be no true positives, and so sensitivity is zero. Hence, there must be no false positives in order to meet the standard that no more than 1 out of 100 total positives is false.

When sensitivity is 1.0, meaning that all tested drug users are identified as such, then specificity must be at least 0.9997 (or 99.97 percent). This figure represents a false positive rate of (1 − 0.9997) = 0.0003, meaning that even with perfect sensitivity, no more than 3 out of every 10,000 negative specimens should result in positive test results. Such precise results are unlikely to occur in practice, given the current state of technology. Even under the extremely favorable conditions used in the AACC study (*18*), 7 out of every 10,000 negative challenges would result in positive test results, a ratio more than twice the acceptable level.

It is also instructive to consider the case at DOT, where 0.006 of the more than 16,000 specimens taken from July 1988 through June 1989 tested positive. Again assuming a desired

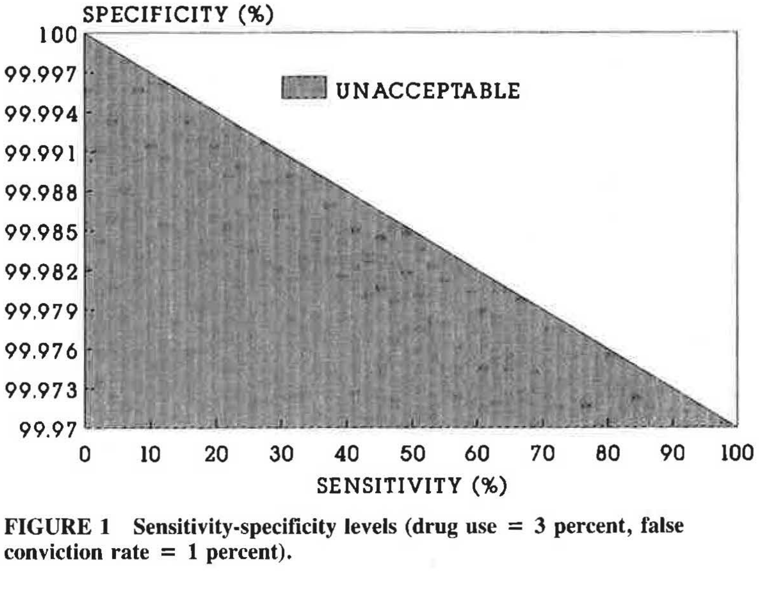

FIGURE 1 Sensitivity-specificity levels (drug use = 3 percent, false conviction rate = 1 percent).

false conviction rate of no more than 1 percent, and substituting the parameters into the appropriate Bayesian equation, the following calculation is performed:

$$P(-|\text{no drugs}) = 1 - [0.00006097 \cdot P(+|\text{drugs})] \quad (8)$$

Assume a sensitivity rate of 90 percent, that is $P(+|\text{drugs}) = 0.90$, the minimum required by DOT regulations. Substituting this into the equation yields a specificity $P(-|\text{no drugs})$ of 0.999945127. The maximum false positive rate, therefore, is $P(+|\text{no drugs}) = 1 - 0.999945127 = 0.000054873$. This result means that there can be no more than 1 reported positive out of every 18,224 truly negative specimens. As this relates to quality control testing, out of every 18,224 blind negative challenges submitted, the laboratories could report no more than 1 positive without violating the desired standards. On the basis of the laboratory accuracy studies observed to date, it would be impossible for most laboratories to be this accurate. Also, given that for the July 1988 through June 1989 period DOT submitted only 79 blind negative challenges at the most (*14*), there is little evidence from DOT's experience that the 1 out of 18,224 ratio has been satisfied.

On the basis of currently published data, therefore, if 3 percent or less of the target population uses drugs, it would be difficult to maintain false negative and false positive rates at levels low enough to ensure that no more than 1 out of every 100 people testing positive is falsely accused.

These results do not mean, however, that drug testing should never be used if one wishes a false conviction rate of no more than 1 out of every 100 positive tests. When the proportion of the population using drugs is higher than 3 percent, then the required sensitivity-specificity combinations will be lower than those shown in Figure 1 (except when sensitivity equals zero).

One likely situation in which substantially more than 3 percent of the target population may be using drugs is when testing is done only for reasonable cause, rather than on a random or universal basis. If supervisors and others are well trained in the signs of drug use, then workers that they refer for testing should be much more likely to be on drugs than those in the workforce as a whole (*17*). Testing for reasonable cause has the added benefit that a direct link between the drug use and performance can be established, providing a much stronger case for discipline than when drug usage is found but no decline in performance can be shown.

Assume, for example, that 50 percent of those individuals tested for cause are actually taking drugs, which is the percentage of DOT employees tested for cause between September 1987 and August 1989 that tested positive (*26*). Figure 2 shows the various sensitivity and specificity combinations that meet the requirements for this situation.

As before, any point on the line in Figure 2 meets the requirements exactly, whereas any point above the line exceeds the requirements. Although the requirements are still high, they are much lower than before and are such that they could be met by laboratories such as those represented in the 1988 JAMA study (*16*). For example, given that 50 percent of those tested are truly on drugs, let us assume a required sensitivity of 90 percent, the level required by DOT regulations (*4*). When this sensitivity is achieved, the specificity would only have to be 99.091 percent. This level is within the capacity of the 1988 JAMA study (*16*) laboratories, which achieved an average specificity of 99.8 percent. Thus, when testing is done for cause, using first-rate laboratories and a rigorous blind proficiency evaluation procedure, drug tests can indeed provide reasonable protection from the false conviction of the innocent.

Assuming laboratory sensitivity and specificity levels at the rates identified in the 1988 JAMA article (*16*), the desired protection against false convictions could be obtained in universal or random testing by use of a two-stage testing procedure. Under such a procedure, no action would be taken against someone testing positive for the first time, except that the individual would be tested again. If the results of the second test were also positive for the same drugs, then it could be assumed that the person is truly taking the drugs, and normal actions for drug usage could be taken.

The rationale is as follows. Assume that the initial target population has a drug usage rate between 0.006 and 0.056, and the sensitivity and specificity on the initial tests are 68.9

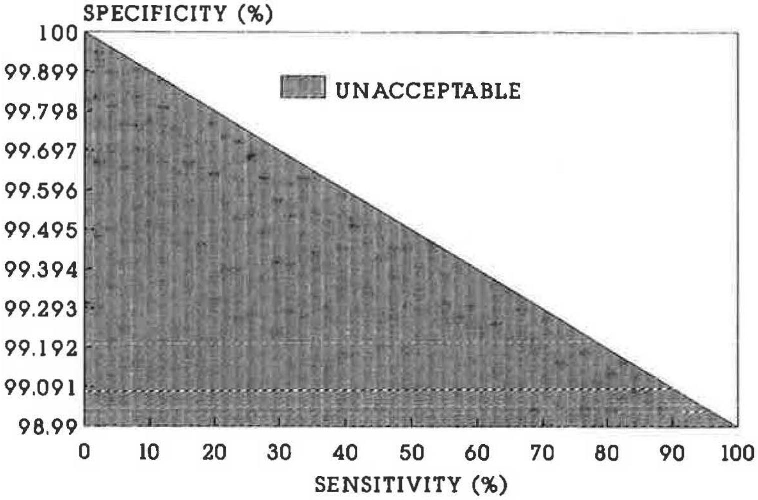

FIGURE 2 Sensitivity-specificity levels (drug use = 50 percent, false conviction rate = 1 percent).

and 99.8 percent, which are the assumptions used in Cases 5 through 8 in Table 1. Thus, from Table 1, the percentage of those testing positive who truly are on drugs ranges from 67.5 to 95.3 percent. The second-stage test is a universal retesting of all those who initially tested positive, so the second-stage target population has a drug usage rate of between 0.675 and 0.953. To be extremely conservative, the usage rate will be set at 0.50. Then, this second-stage target population has the same usage rate as that illustrated for a target population of individuals tested for cause, and similar results apply. (Note that the two-stage procedure assumes that the initial false positives are not the result of some underlying condition that will cause the incorrect results to recur on the second test.)

This result means that current technology is sufficient to obtain no more than 1 false positive out of every 100 positive tests if the target group has a usage rate of at least 0.50. This condition may hold when testing is done for cause or if second tests of those initially testing positive are conducted.

CONCLUSIONS AND POLICY IMPLICATIONS OF THE STUDY

The initial conclusion of this analysis is that allegedly accurate tests for abused drugs can be inaccurate to a disturbingly high degree, under circumstances that may sometimes occur in transit. For example, consider the laboratory accuracy rates from the most favorable published blind study to date, and current drug usage rates of railroad, transit, and DOT employees. Using these averages, 1 out of every 15 positive tests of railroad workers would be false, as would be 1 out of 10 positive tests of employees at one transit agency, and 1 out of 3 positive tests of DOT employees.

Such potential inaccuracies should serve to encourage both governmental regulators and transit operators to proceed with the utmost care in implementing drug testing programs. Further, the findings demonstrate the need to alert transit operators, employees, and their unions that seemingly reliable drug tests can be inaccurate and to educate all groups concerning methods for assessing accuracy.

Moreover, it is important for policy makers to be aware of the potential problems and to consider the implications in their decision-making processes. Failure to do so creates the potential for lost lawsuits and arbitrations and could cost many innocent workers their jobs and many unwitting agencies good employees. Further, failure to do so may violate the principles of our legal and workplace jurisprudence systems by allowing convictions with insufficient evidence; this could lead to political pressure sufficient to outlaw drug testing even in justifiable cases.

It is important that the proportion of workers falsely accused decreases when a higher percentage of the population being tested is truly on drugs. If, for example, 50 percent or more of the target group is truly taking drugs, then it is possible to ensure a rate of no more than 1 false conviction out of every 100 people testing positive. Thus, if testing is limited to high-usage groups, the results can provide an acceptable degree of accuracy.

One common case in which drug usage in a sample may be high would be for workers tested for reasonable cause. In DOT's testing experience for reasonable cause, for example, 50 percent of those tested have tested positive.

If random or universal testing must be used for a group with a low drug usage rate, acceptable accuracy can be obtained through the use of a two-stage process. No action would be taken concerning those who test positive for the first time, other than to retest them. Positive results for the same drugs on the second test would often provide acceptable accuracy, because the retested group would often have a drug-use rate exceeding 50 percent.

Conclusions concerning for-cause and two-stage testing assume that laboratory sensitivity and specificity rates are at least as high as the averages from the 1988 JAMA study (*16*), and that target populations have drug usage rates of at least 0.50. The two-stage process also assumes that errors are random and not the result of conditions that will cause them to recur for the same individuals.

Whether it is decided to test randomly, universally, or on the basis of probable cause, a Bayesian methodology should be used. Such a framework will ensure that the test results are sufficiently specific and sensitive to achieve the desired PPV. If groups with different abuse rates are being tested, then the procedure should be applied to each group separately.

DOT has not directly addressed the most important accuracy standard, that of the minimum acceptable PPV. The PPV is the percentage of all positive tests in which drugs are truly present. Thus, if DOT wishes to regulate the accuracy of test results with the objective of protecting the innocent as well as identifying the guilty, then it needs to set explicit standards for the PPV or, equivalently, for the false conviction rate, (1 − PPV). The false conviction rate is the percentage of all positive tests in which drugs are absent.

This work has used accuracy data under conditions when chain of custody was not a major problem and when no nondrug substances could produce positive test results, because all challenges contained only the drugs for which tests were being conducted. When such factors are a significant consideration, as they would be during actual drug tests of real workers, the reliability of the test results will usually be worse than those from laboratory proficiency studies.

Because some will quarrel with our estimates of drug use, sensitivity, and specificity rates, the primary emphasis of this paper may be obscured. The average rates believed to be the most applicable to transit drug testing were used. These rates were based on empirical evidence, from studies published in reputable sources. When more relevant average rates become available, they should be used in place of the ones used herein. Further, regardless of whose average estimates are used, conclusions about the extent of error that are based on averages are not applicable to a particular situation. False conviction rates for a specific organization can only be estimated if the underlying Bayesian methodology is combined with data specific to that particular case

Our main message is that appropriate rates should be used in a Bayesian framework to develop estimates of false conviction rates, and that the maximum acceptable false conviction rate should be used in setting the required combinations of sensitivity and specificity. That is, the rates for PPV, sensitivity, specificity, and drug usage form a system. The key rate is false conviction rate (1 − PPV), which is affected by the levels of the other three rates. Thus, using a Bayesian framework one can either determine the actual false conviction rate from the other three rates or determine the acceptable combinations of sensitivity and specificity given an actual drug usage rate and the desired maximum false conviction rate.

The use of abused drugs by the nation's transit workforces is indeed a serious problem that must be addressed on many fronts. In proper circumstances, urine testing is a valuable weapon for decreasing drug use, and its use for safety-sensitive employees is recommended. However, although testing should be available, it should be used sparingly and with the utmost care. The recent rush toward routine universal drug testing may result in personal and economic costs far in excess of any potential benefit.

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DISCUSSION

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Barnum and Gleason draw two general conclusions. First, they state that available data indicate that drug tests will result in significant false positives and false negatives. Second, they note that, using a Bayesian analysis and available data, drug testing will result in a very high percentage of those identified as using drugs being falsely identified. For example, the paper states that under the DOT program for testing its own employees, as many as one-third of those identified as positive may be falsely identified. DOT personnel believe that the paper relies on data that is invalid for purposes of analyzing either its internal testing program or the recently initiated testing in the transportation industry resulting from DOT regulations. We also believe that the Bayesian analysis is an inappropriate technique for analyzing testing programs whose primary purpose is deterrence.

The basis for the authors' analysis is data taken from a 1988 JAMA article on the results of blind and open proficiency tests of laboratories conducted by NIDA in 1986 and 1987. The proficiency tests conducted at these laboratories in 1986 and 1987 are not the same as proficiency tests conducted at NIDA-certified drug-testing laboratories; as the authors acknowledge, confirmatory analysis may not have occurred and any confirmatory analysis that did occur may not have been conducted using GC/MS methodology. The proficiency testing data found in the JAMA study can only be applied to drug testing conducted in laboratories using procedures and analytical methodologies identical to those in the study. Applying these data as baseline data for the accuracy of drug testing in laboratories using NIDA-mandated procedures and methodologies (to include immunoassay screening and GC/MS confirmation) is incorrect.

There are a number of problems with relying on this data to analyze current DOT testing programs.

The JAMA study (*16*) was a basis for the Department of Health and Human Services (HHS), NIDA, decision to issue very strict guidelines for drug testing of federal employees and to implement a laboratory certification program in April 1988. The NIDA guidelines are used in the DOT employee testing program and were adopted with minor modifications (reviewed by NIDA) for DOT's industry drug testing rules. Among other things, the following requirements must be met:

1. Drug testing laboratories must be HHS/NIDA certified. NIDA certification requires thorough documentation of laboratory personnel, procedures, and facilities; open and blind proficiency testing programs; onsite inspection by NIDA inspectors; and a comprehensive quality assurance program for all aspects of specimen processing.
2. GC/MS confirmatory testing is required for all samples that screen positive on immunoassay. This virtually error-free test is an extremely important element of any reliable testing program. Over half of the laboratories in the JAMA study did not use it.
3. Drug testing is authorized only for five drugs [cocaine, marijuana, opiates, phencyclidine (PCP), and amphetamines], and specific cutoff levels for a positive result are mandated. The NIDA-approved drug testing protocols are used to ensure standardization of positive test results. Cutoff levels are established for both immunoassay and GC/MS analysis.
4. Reanalysis (retest) of positive specimens is authorized. Employees may request reanalysis of a positive specimen. The reanalysis can be conducted at another NIDA-certified laboratory or at the NIDA laboratory that conducted the original analysis. Reanalysis of over 100 positive specimens in the DOT employee drug testing program has resulted in affirmation of the positive result in all cases.
5. A Blind Proficiency Testing Program is required of all employers. Blind quality control specimens (both specimens containing no drugs and specimens containing drug metabolites) are submitted to the laboratories by employers. The quality control specimens are indistinguishable from employee specimens. Results of the laboratory's performance on the quality control specimens are monitored by the employer, and unsatisfactory laboratory performance must be reported to DOT.
6. Medical Review Officer (MRO) verification of laboratory positives is mandated. Every laboratory positive must be reviewed by an MRO to ensure that there are no documentation or other errors in the testing process. The MRO verification process also permits employees to present documentation of an authorized medical use of a controlled substance. This verification process is an additional safeguard for employees whose specimen tests positive at the laboratory.

The testing procedures reflected in the JAMA studies are not comparable to, and are substantially less stringent than, the testing procedures used by DOT for its own employees and in its testing program for private sector transportation employees.

The DOT federal employee drug testing program was implemented in September 1987. The laboratory used for drug testing was certified by the Department of Defense (DOD). NIDA required the use of DOD-certified laboratories until the NIDA laboratory certification program was implemented. Extensive data are available on the blind proficiency testing program conducted by the Armed Forces Institute of Pathology (AFIP) for all DOD-certified drug testing. The DOD certified both U.S. military-operated laboratories and commercial laboratories used by the Department of the Army and the U.S. Coast Guard for drug testing. A summary of the AFIP blind proficiency test data for January 1988 through June 1989 is presented in Table 2.

DOT has also conducted a blind proficiency testing program of the NIDA-certified laboratory used for DOT employee testing. The results of this blind proficiency testing program for July 1989 through February 1990 are summarized in the following table.

	No. Tested	*Correct*	*Error Rate*
Negatives	482	482	0.00
Amphetamines	21	21	0.00
Opiates	19	19	0.00
PCP	19	17	0.11
Cocaine	23	23	0.00
THC	34	34	0.00

Total False Pos Rate 0.00
Total False Neg Rate 0.017

In litigation challenging the reliability of drug testing in HHS-certified laboratories in which plaintiffs relied on Bayes' theorem, the Director of Workplace Initiatives at NIDA stated

TABLE 2 AFIP BLIND PROFICIENCY TEST DATA FOR JULY 1989 THROUGH FEBRUARY 1990

Laboratory	Number of Samples	Number Correct	False Negative Rate
	Negatives		
NCA	2,476	2,476	0.00
EHRT	2,454	2,454	0.00
CL	1,725	1,725	0.00
	Amphetamines		
NCA[a]	0		
EHRT	55	51	0.0727
CL[a]	0		
	Opiates		
NCA[a]	0		
EHRT	78	78	0.00
CL[a]	0		
	PCP		
NCA[a]	0		
EHRT	86	86	0.00
CL[a]	0		
	Cocaine		
NCA	165	165	0.00
EHRT	166	166	0.00
CL	111	111	0.00
	THC		
NCA	470	469	0.0021
EHRT	463	459	0.0086
CL	336	333	0.0089
Total False Negative Rate			0.0062

NOTE: NCA = Northwest Toxicology Associates. EHRT = Environmental Health, Research, and Testing. CL = Compuchem Laboratories.

[a] Blind spikes for amphetamines, opiates, and PCP were not tested at Army contract laboratories because the Army program only tests for cocaine and THC.

(in a September 22, 1988, declaration) that "the military has used blind proficiency testing since 1983 with GC/MS as the confirmatory test and has generated no false positives in over 40,000 tests. Thus, the predictive value of true positives under Bayes' theorem is virtually 100 percent."

The above documentation shows that the false positive and false negative rates obtained at the NIDA laboratories in the AFIP and DOT blind proficiency testing programs are significantly different from those reported in the JAMA study. These data validate the accuracy of drug testing at NIDA-certified laboratories.

There are many other problems or errors with the paper that are worth brief mention here:

1. The JAMA article study covered testing for drugs not included in the DOT program or regulations. The error rates for those other drugs appeared to be higher. It appears, therefore, that the error rate relied on by the authors for analysis of DOT testing should be lower.
2. As noted above, the DOD has conducted blind proficiency testing in its military drug testing laboratories using immunoassay and GC/MS methodologies for the past 6 years. The Navy tests cited by the authors that were declared "scientifically unsupportable" in 1982 were not conducted using GC/MS confirmatory analysis.
3. The data used in the paper for estimating potential drug use in the transportation industry are not a valid basis for the conclusions reached. For example, some of the estimates appear to be based on preemployment drug testing that, as a scheduled test, is not a reliable indicator of overall drug use. It will not identify users who can stop long enough to get a negative on a test. Recent data from the 1988 NIDA Household Survey on Drug Abuse indicate that approximately 12.5 percent of adults employed in transportation occupations have used illegal drugs.

Finally, it seems highly inappropriate to use a Bayesian analysis on a drug testing program that stresses deterrence. Under the Bayesian approach, even though the actual number of errors essentially stays constant, the number of errors becomes an increasingly higher percentage of the total number of positives as the actual number of real positives decreases. In other words, the Bayesian analysis penalizes a program that effectively deters usage—the ultimate goal—by making it appear that the best program has the worst rate for falsely identifying drug users. An appropriate analysis would simply indicate the actual number or rate of false positives. More important, because the data presented indicates that the paper should have used a predictive value of virtually 100 percent—if not 100 percent—under the Bayes' theorem, the conclusion of the paper should have been: transit industry testing will have virtually no false positives.

AUTHORS' CLOSURE

We have carefully analyzed Allen's discussion of our paper. Our most important conclusions are these. First, the discussant provided no valid evidence about laboratory accuracy in transit, and we are still convinced that drug tests sometimes may be very inaccurate in current transit agency testing. Second, Allen missed the primary intent of our paper. Our purpose was not to estimate average drug test accuracy in the transit industry but to present a methodology for ensuring acceptable accuracy at individual transit properties. Third, we were able to identify only one of the sources that the discussant utilized. In this case, we discovered that she had badly misinterpreted the data. Furthermore, Allen misrepresented a number of the points we made in our paper. Consequently, we are concerned about the accuracy of all of the information that she presented. Our discussion of these three conclusions, and a number of other points of disagreement, are covered in this closure.

In her discussion of our paper, Allen's response begins with a totally incorrect statement about our conclusions. In describing the conclusions that we supposedly drew, she states:

> First, they state that available data indicate that drug tests will result in significant false positives and false negatives. Second, they note that . . . drug testing will result in a very high percentage of those identified as using drugs being falsely identified.

Neither of these conclusions appears in our paper. First, we never said that drug tests would result in significant false positives and false negatives. In fact, we showed that inaccurate results could occur in situations where the false positive and false negative rates were both very low. Second, we were very careful not to claim that drug testing *will* result in high percentages of those testing positive being falsely identified. Indeed, we explicitly stated

> Very importantly, these false conviction rates are based on our estimated average rates for drug usage, sensitivity, and specificity and are not necessarily applicable to any particular transit agency. But all of our estimated rates are ones that could occur in some circumstances. Because of the extremely serious consequences of being convicted of drug use, an employer would be wise to determine that these estimated rates, or similar rates, do not apply before acting on positive drug test results.

Allen also states that our paper should have concluded that "transit industry testing will have virtually no false positives." We disagree. As discussed next, we are even more strongly convinced than before that seemingly accurate tests for abused drugs may sometimes be inaccurate to a disturbingly high degree in current transit industry testing. We feel that it is even more appropriate to use the methodology we suggested in the original paper, by which transit decision makers can correctly set desired accuracy standards for their own organizations, thereby easily avoiding these potential inaccuracies.

The discussant's statement attempted to show the accuracy of NIDA-certified laboratories. However, it neglected to mention that, since January 1990, transit agencies have not been required to use NIDA-certified laboratories. Therefore the laboratory accuracy data that Allen presented are inapplicable to transit. That is, transit agencies were initially required by DOT (through UMTA regulations) to use laboratories certified by NIDA for all of their drug testing. These laboratories had to confirm all positive test results, using GC/MS for all confirmations. On January 19, 1990, after less than a month of drug testing under these regulations, UMTA's authority to impose requirements was revoked by the courts (*1*). Thus, at the time of this writing, April 9, 1990, federal regulations do not prevent transit system drug testing from being conducted by anyone, and from using any confirmation method desired. For example, one management company that operates a large number of transit systems has told its resident managers that they may use any laboratory in which they have confidence, whether or not it is NIDA certified. Transit drug testing is regulated by widely varying local laws, some very strict and others very lenient. Testing at many systems is not regulated by government in any way. Thus, the average accuracy of the transit industry's drug testing might be comparable to the 1985 JAMA study, the 1988 JAMA study, or some other level. Consequently, accuracy levels used in our paper, which are based on the 1985 and 1988 JAMA articles, might be higher or lower than the average levels actually present in the industry at this point in time.

Moreover, we are concerned about whether the DOD-certified laboratory accuracy averages that Allen presented would be applicable even if transit were required to use NIDA-certified laboratories. These data show a quantum leap in accuracy when compared to all other blind laboratory proficiency studies. We would be more reassured about the validity of the data if they had come from an article in a well-respected refereed journal, or from another source that had been subjected to rigorous refereeing, and if the data had been gathered by a disinterested party. The military results may or may not be applicable to DOT-required testing at NIDA-certified laboratories, but there appear to be important differences between the DOD and DOT laboratory procedures, at least on the surface (*2,3*). For example, although two tests are required under the DOT procedures (*3*), Irving (*2*) states that the Navy requires three tests before a specimen is considered positive. The extra test should significantly lower the false positive rate. Moreover, DOD cutoff concentrations for some drugs appear to be higher than DOT cutoff concentrations (*2,3*), which would also make it less likely that the DOD laboratories would have false positives when compared to the laboratories used by DOT. There are other differences as well, but these two should serve to illustrate the fact that DOD results may well be more accurate than NIDA results. It is completely invalid to estimate one from the other without a much more detailed examination of the procedures, refereed by experts in the field. Therefore, in our opinion, the information presented does not demonstrate the accuracy of DOT drug testing procedures at NIDA-certified laboratories, because too many questions remain unanswered.

If, at some future time, transit drug tests are indeed proved to have no false positives, then Bayesian analysis would not be necessary, because the false conviction rate would be zero. However, there must be zero false positives, not, as Allen states, "virtually no false positives," especially where drug usage rates are low. For example, if DOT testing of its own employees reduces their drug usage by the same percentage that occurred in the military, DOT's usage rate will drop from 0.6 percent to less than 0.1 percent. Incidentally, 0.1 percent is the rate found during U.S. Customs Service random testing of its current employees, so having only one drug user out of every 1,000 employees is attainable (*4*). Using this 0.1-percent usage rate and the concepts we discussed in our paper, there could be no more than 1 false positive out of every 98,901 drug-free specimens, if we wanted to falsely convict no more than 1 out of every 100 people testing positive. Or, assume it is required that there be no more than 1 false positive out of every 1,000 positive test results, a level the unions might find more reasonable than only 1 out of 100. Using the 2.6-percent drug usage rate recently found at a large transit system and DOT's maximum allowable false negative rate of 10 percent (*3*), then there could be no more than 1 false positive out of every 41,582 drug-free specimens. In either case, even the military's alleged 40,000 tests of drug-free specimens without a false positive would not be enough to attain acceptable accuracy, even if the military results were applicable. Thus, Bayesian analyses should be performed unless there are no false positives at all.

Most important, however, the discussant's statement did not address the primary intent of our paper. Our main purpose was not to estimate drug test accuracy in the transit industry but to present a methodology for ensuring acceptable accuracy. Because this point is so important, we repeat here the critical paragraphs.

> Because some will quarrel with our estimates of drug use, sensitivity, and specificity rates, the primary emphasis of this paper may be obscured. The average rates believed to be the most applicable to transit drug testing were used. These rates were based on empirical evidence, from studies published in reputable sources. When more relevant average rates become available, they should be used in place of the ones used herein. Further, regardless of whose average estimates are used, conclusions about the extent of error that are based on averages are not applicable to a particular situation. False conviction rates for a specific organization can only be estimated if the underlying Bayesian methodology is combined with data specific to that particular case.
>
> *Our main message is that appropriate rates should be used in a Bayesian framework to develop estimates of false conviction rates, and that the maximum acceptable false conviction rate should be used in setting the required combinations of sensitivity and specificity.*

Our article presented an easy solution to the problem of insufficient accuracy, that Allen apparently missed in her concern about the various laboratory proficiency studies. The solution is introduced in the second and most important part of our study, the section entitled "Methodology for Developing Acceptable Predictive Probabilities." It is easy to lower the false conviction rate by retesting a second time. That is, a positive screening test is already automatically followed by a confirmation test. To lower the false conviction rate still further, all that is necessary is to follow a positive confirmation test with a second confirmation test. For cases in which there is extremely low drug usage, or in which extremely low rates of false convictions are required, a positive result on the second confirmation could be followed by a third confirmation. To decide on the number of confirmations needed, it would be necessary to do a Bayesian analysis with the desired parameters. The multiple testing must not be optional, nor should it be conducted on a request by the involved employee, but it must automatically occur when the screen and first confirmation are positive. This suggestion is a variation on the two-stage procedure that we discussed at length in the paper; it accounts only for laboratory errors, not for errors in the chain of custody or contaminated vessels or other problems occurring outside the laboratory itself. The procedure suggested in the article accounts for these external problems as well.

We also wish to comment on the discussant's belief that "Bayesian analysis is an inappropriate technique for analyzing testing programs whose primary purpose is deterrence." We disagree. As we noted in the paper, both the American legal system and its system of workplace jurisprudence are based on the principle that a person is assumed innocent until proven guilty with compelling evidence. Under our legal and industrial jurisprudence systems, for example, it is unlikely that a defendant would be convicted if there were only a 50-percent chance that the prosecution's evidence was true, but it is likely that a defendant would be convicted if there were a 99.9-percent chance that the evidence was true. Bayesian analysis identifies the correct probability that the evidence provided by a positive drug test is true, and we ignore it to the peril of our system of justice. It is highly appropriate that it be used.

Allen is correct in stating that as drug usage declines, the number of false positives remains essentially constant although the false conviction rate increases. But this fact is irrelevant. It assumes that we must choose between a situation with high drug use and low false conviction rates and one with low drug use and high false conviction rates. We can easily have both low use and low false conviction rates by requiring multistage testing in appropriate situations. Bayesian analyses tell us, for given rates of usage and desired ceilings on rates of false convictions, when multistage testing is necessary. Thus, although we hope DOT's drug testing program will lower drug abuse rates, the simultaneous application of Bayesian techniques will ensure that employees testing positive are indeed likely to have taken drugs, by adjusting the retesting requirements for the drug abuse rate of the population being tested.

The discussant misrepresented several other statements in our paper. She states that we acknowledge that confirmation tests may not have occurred in the 1988 JAMA study. The opposite is true; we stated that "It appears that the laboratories in the 1988 JAMA study did conduct confirmation testing of specimens that initially screened positive, and the most frequently used confirmation method was GC/MS." Also, Allen says that some of our estimates of drug use appear to be based on preemployment tests. To the contrary, all of the estimates we used in the analyses were based solely on drug tests of current employees.

Moreover, while we don't want to debate numbers, Allen makes the following statement about drug use: "Recent data from the 1988 NIDA Household Survey on Drug Abuse indicate that approximately 12.5 percent of adults employed in transportation occupations have used illegal drugs." This is not true. The actual results from NIDA indicate that 12.5 percent of the surveyed males between 18 and 40 in the transportation industry said that they had used some illicit substance in the past month, with the illicit substances including the nonmedical use of stimulants, sedatives, tranquilizers, or analgesics (*5*). Figures for all adults in transportation are not even available. For all occupations, however, males were almost twice as likely as females to say they had used some illicit substance, and workers between 18 and 35 were almost six times more likely than workers over 35 to say they had used some illicit substance (*5*). The usage rate would be even lower if only illicit drugs, which is all that DOT is testing for, are considered. In short, not only has the discussant incorrectly identified the reference group and the illicit substances to which the 12.5-percent figure applies, but also, by saying it represents the drug use rate of all adult transportation workers, has drastically overestimated drug use by transportation employees. We assume that this error was unintentional and not a conscious attempt to inflate the drug-use figures. But, if Allen could make so basic an error in so simple a data situation, it calls into question the validity of all of her data, much of which is very complex and requires expert interpretation. Because the discussant did not provide complete references for any of her sources, we were not able to check the accuracy of the information, except for the one case just cited. However, the error that we did discover reemphasizes our earlier point about the laboratory data presented: the information should not be accepted as valid until subjected to a rigorous and complete review by neutral experts in the field of laboratory proficiency studies.

In closing, we are pleased that DOT, through Allen, chose to offer a discussion of our paper. It introduced new data that we were unaware of and provided us with the opportunity to correct misunderstandings that our original paper inadvertently generated. We feel that DOT personnel are working hard to make their drug testing procedures accurate, and we hope that they and others will use our suggestions to further improve the certainty of error-free tests.

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Impact of Labor Contract Provisions on Transit Operator Productivity

SUBHASH R. MUNDLE, JANET E. KRAUS, AND GLENN A. HOGE

The research was designed to obtain a better understanding of the cost impacts of different labor contract provisions. Three main items within the labor contract influence costs and productivity: work rules, absenteeism, and fringe benefits. The cumulative impact of the provisions was measured using the ratio of pay hour to platform hour. To quantify how these contract provisions affect costs, an extensive literature review was conducted, followed by case studies of the transit systems in Indianapolis, New Orleans, and Philadelphia. The contract provisions added an average of 47 min to the basic service hour, measured in terms of platform time. A system must therefore pay for an average of 1 hr 47 min to put 1 hr of service on the street. Performance within the three case study systems ranged from a low of 1 hr 36 min to a high of 2 hr 4 min. The research demonstrated the importance of considering the three components of labor contract provisions simultaneously; focusing on one element does not measure the overall productivity impact accurately. When local cost reduction and productivity improvement strategies are developed, they should encompass all labor contract provisions.

Labor costs account for a large portion of the operating expenses in bus transit service. Three main items within the labor contract influence costs and productivity: work rules, absenteeism, and fringe benefits.

Work rules are the regulations, principles, and guidelines that set parameters on how transit managers can allocate their resources. Work rules generally fall into two categories:

1. Restrictive—constraining the hours of work that may be performed, and
2. Compensatory—providing premium payment for work done in excess of what is established.

Absenteeism is the condition that a worker is not available for work. It can take two forms:

1. Scheduled—because of vacations, holidays, or other situations for which management has received advance notice of the absence, and
2. Unscheduled—because of illness or not reporting to work and not providing advance notice.

Fringe benefits include the host of programs available to workers as part of their employment package, such as vacation pay, holidays, sick leave, health and life insurance, retirement, free transportation, and uniform allowance. Incentive plans offered by some transit systems would be included in this category.

Past research has focused on one or two of these issues. Although it has yielded valuable findings, it has not presented a comprehensive review of all labor costs. Nor have the prior studies quantified the total impact of all the provisions in a typical contract.

The objective of this research effort was to obtain a better understanding of the cost impacts of different contract provisions. The research was conducted in three steps. The first was a literature review, in which the findings from past research efforts were summarized to identify the remaining research needs. The second step included a detailed analysis of the cost and productivity impacts at three selected transit systems. In the final step, the findings from the case studies were synthesized.

LITERATURE REVIEW AND STUDY DESIGN

This project was designed to study the impacts of all contract provisions on the ratio of pay hour to platform hour. To determine what research had already been done, the literature on the subjects of work rules, absences, and fringe benefits was reviewed. The findings are summarized in the following subsections.

Work Rules

The impact of work rules on transit productivity has received more attention than any other issue included in this review. The number and complexity of work rules have increased over the years. One researcher (*1*) tied the expansion of work rules and the concurrent decline of labor productivity to a significant part of the transit industry's losses during the 1970s. Much of the literature on work rules deals with the use of part-time operators (PTOs). When PTOs were introduced, early research focused on how they could be used to ease the labor requirements of the peak periods (*2*). It was found that potential cost savings were greatest when the PTOs, who were not subject to the same work rules as their full-time operator (FTO) counterparts, were used for tripper runs.

As PTO usage became more widespread, research focused on the lessons learned from the earliest systems that employed them. Findings were often in direct conflict with each other, with some systems reporting that PTOs had higher absence and accident rates than FTOs and others reporting the opposite (*3,4*). Transit systems using PTOs reported cost savings, mainly because the part-timers were subject to less restrictive work rules. However, it was found that potential savings could be eroded by concessions to gain the right to hire PTOs.

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Absences

Considerable emphasis has been given to the issue of operator absences. Studies have found that transit operator absences have a substantial impact on productivity and cost. One study (*5*) found that the cost of all absences was equal to about one-fourth of the total amount provided in federal operating subsidies during the study year. Costs are driven by the need to pay absent employees as well as the others who are paid to take their places. It was found that, although the absence problem is widespread, most absences are accounted for by a small group of employees. At one system, 1 percent of the employees accounted for 10 percent of the absences (*6*).

Several studies (*7,8*) examined the causes of absenteeism. Fatigue and the desire for increased leisure time were found to be important reasons for high rates of absence. Stress played a limited role in absenteeism. Using overtime employees to fill vacant runs added to the absenteeism problem because the overtime employees subsequently became absent to recover from long shifts or to make up for lost leisure time.

A good deal of effort has been spent studying uses for extraboard operators. Research has focused on when to use extraboard drivers and when to use regular operators on overtime. Several techniques for optimal extraboard usage have been developed and offer significant potential savings (*9*).

Fringe Benefits

The current literature is limited in its discussion of fringe benefits. Only three sources dealt with benefits as a primary topic (*10–12*). All three focused on incentive plans as a way to reduce costs. These plans, also known as gain-sharing programs, offer rewards in return for the achievement of tangible goals. They are offered to reduce absenteeism. All three sources cautioned that incentive plans should not be used as a substitute for good benefits or sound management.

Other research noted that fringe benefit costs make up a large portion of total system costs in many cases. Fringe benefits tend to represent a much greater share of compensation costs in the public transit sector than in the private sector (*13*). However, PTOs were seen as a partial solution to the high costs of fringe benefits because they are not eligible for most of the benefits received by FTOs.

ANALYSIS FRAMEWORK

Improvements in cost efficiency can be achieved through more efficient labor utilization. An important indicator of transit operator utilization is the ratio of pay-hours (an input statistic) to platform-hours (an output statistic). These two statistics are defined as follows:

1. Pay-hours represent all hours for which a driver is paid. In addition to platform-hours, there are hours for other time associated with revenue service. There are also hours associated with holidays, vacations, illnesses, and other paid absences.
2. Platform hours represent the time an operator is on board the bus, either preparing for service or carrying passengers.

The ratio of the two statistics reflects the productivity of an hour of service—that is, the amount of pay time over and above scheduled service. Control of the factors influencing this ratio has a major impact on labor utilization efficiency and operating costs.

Total driver pay-hour costs accumulate in several key steps. At each step, 1 hr of service continues to cost more to provide. The basic platform hour, also known as a service hour or work hour, is the basic product that the transit system delivers to its patrons.

It costs much more than the cost of one platform-hour to provide 1 hr of service. Various work rule constraints require paying additional time to operate the scheduled service. Adjustments must be made to operate the service despite operator absences. In addition, expenses must be incurred for operator benefits such as health insurance and pension contributions. The step-by-step progression of this framework is shown in Figure 1.

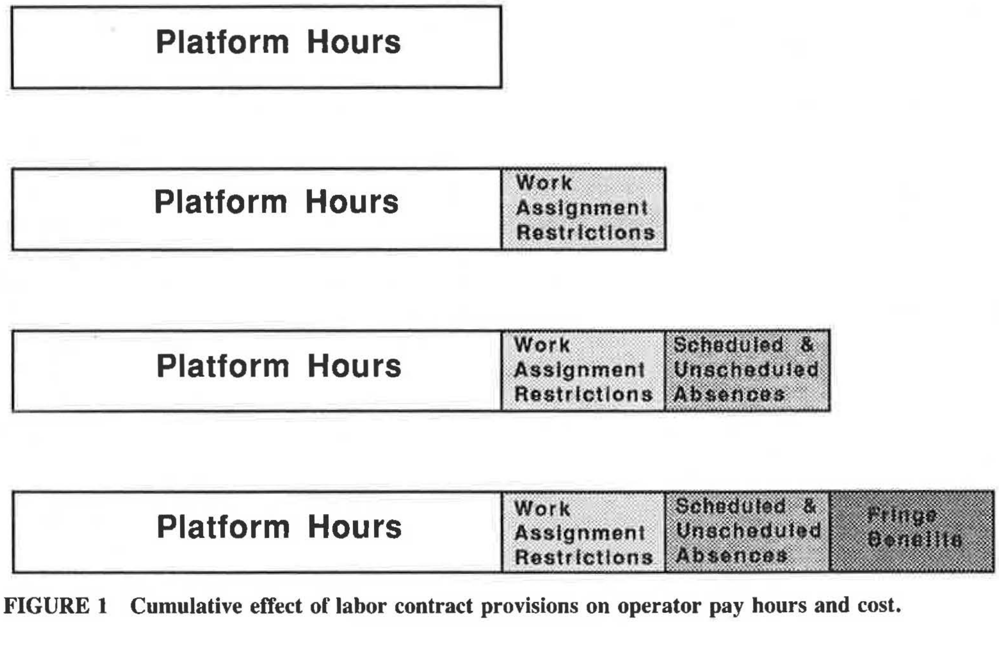

FIGURE 1 Cumulative effect of labor contract provisions on operator pay hours and cost.

Definitions and Information Needs

As mentioned earlier, there are three basic categories of labor contract provisions: work rules, absences, and fringe benefits. In this study, common definitions were developed for each category to permit the standardization of collected data among systems. The definitions used in the case studies were based on findings from the literature review. In cases where multiple modes were operated, only motorbus operators were studied. The analysis was done for fiscal year 1987.

Work rules govern how work is assigned, scheduled, and performed at a transit system. A study by the University of Tennessee (*14*) defined this as a broad subject covering six categories of work procedures. Work rules regarding the scheduling of operator assignments were most pertinent to this study. The UMTA Section 15 report lists work rules associated with the pay hour, and their costs, on Form 321. Information was requested from the case study systems in a format similar to that of Form 321, separately for FTOs and PTOs.

In the literature review, sources on absences focused on distinct aspects of the issue; a complete definition was not available from any one source. Thus, the following definitions were developed for this study:

- *Scheduled.* A scheduled absence was defined as any day on which an operator ordinarily would report to work but does not, under prior arrangement. This type of absence includes vacation and holiday allowances, funeral leaves, military leaves, maternity and paternity leaves, jury duty, court appearances, union business, suspensions, and requested days off. It excludes weekly scheduled days off.
- *Unscheduled.* An unscheduled absence occurs when an operator fails to report to work without giving management advance notice of the absence. There are two further distinctions within this category:
  - —*Involuntary.* An involuntary absence occurs when an operator is unable to report to work due to circumstances beyond his or her control. This type of absence may be caused by illness on or off duty, injury on duty (IOD), injury outside the workplace, or family emergency.
  - —*Voluntary.* A voluntary absence occurs when an operator is able to report to work but chooses not to do so. It includes being absent without leave (AWOL) and abusing sick leave or other work rules.

The data collected on absences included separate information for FTOs and PTOs.

Fringe benefits are programs available to transit workers as part of their employment package. Included are health, medical, and dental insurance; retirement; free transportation; uniform allowances; and worker's compensation. Vacation, holiday, and sick leave policies are often found within the fringe benefit framework; however, for this analysis, they are classified under absences. This effort relied heavily on the detailed definitions of fringe benefits compiled by The Urban Institute (*15*). The costs of all fringe benefits were quantified separately for FTOs and PTOs.

Site Selection

The study resources were sufficient to conduct three case studies. The systems selected were

- Indianapolis Public Transportation Corporation (IPTC), Indianapolis, Indiana;
- Regional Transit Authority (RTA), New Orleans, Louisiana; and
- Southeastern Pennsylvania Transportation Authority (SEPTA), Philadelphia, Pennsylvania.

Case study reports were prepared separately for each of the three transit systems. Key findings are synthesized in the following section, organized according to the three components of labor contract provisions.

SYNTHESIS OF FINDINGS

Work Rules

Each of the three case study systems provided detailed information on the number of operator hours in a wide variety of work rule categories. These hours were compared with a base number of platform hours. The total hours associated with work rules were related back to platform hours to calculate the first component of the ratio of pay-hours to platform-hours. The impact of work rules on this ratio at each system is shown graphically in Figure 2 and summarized as follows:

System	*Work Rules as a Percentage of Platform Time (%)*
IPTC	38.89
RTA	19.50
SEPTA	33.82
Average	30.74

On average, approximately 31 percent more pay-hours were needed because of work rules. This 31 percent added 18 min of pay for every hour of platform service.

Some work rule categories were significant at one system but not necessarily at the others. Other categories, however, had a consistent impact at all three. The five largest categories are presented in Table 1, ranked by the average percentage of platform time.

Spread-time premiums, the largest individual category on average, was the largest work rule category at IPTC and SEPTA yet ranked eighth at RTA. Scheduled overtime premiums was a significant category at all three systems and the second largest average category. Unscheduled overtime premiums, the third largest average category, had a substantial effect at two systems. Report time had a noticeable effect at all three systems. The fifth category, the Fair Labor Standards Act (FLSA), was one of the largest categories at RTA but had a minuscule effect at the other two systems. The FLSA requires that anyone working over 40 hr per week must be paid overtime rates. In Table 1, the percentages indicate the difference between the overtime payments made under the contractual agreement and the payments required by the FLSA.

Absences

Data were collected from the three case study sites regarding time lost because of operator absences. The effect of absences on the ratio of pay-hours to platform-hours was calculated in

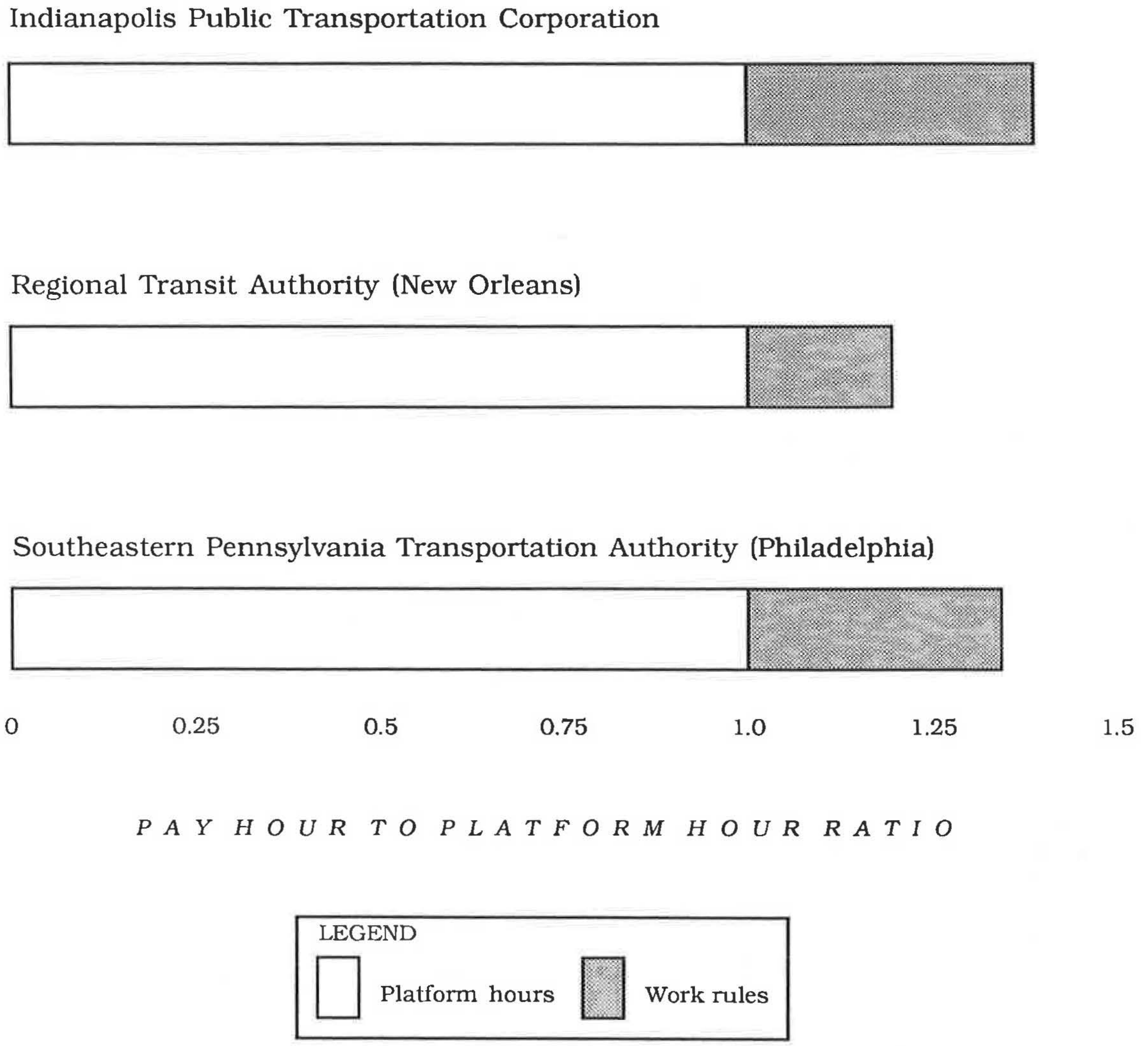

FIGURE 2 Effect of work rules on the ratio of pay-hours to platform-hours.

TABLE 1 RANKING OF WORK RULE CATEGORIES

	Percentage of Platform Time			
Five Largest Categories	IPTC	RTA	SEPTA	Average
Spread-time premiums	10.67	0.58	8.47	6.57
Scheduled overtime premiums	6.85	4.60	5.06	5.50
Unscheduled overtime premiums	5.18	0.03	8.13	4.45
Report time	2.70	1.87	4.15	2.91
Fair Labor Standards Act	0.01	4.55	0.00	1.52

a manner similar to that used for work rules. Results are presented graphically in Figure 3 and summarized as follows:

System	*Average Absences per Operator (days)*	*Absences as a Percentage of Platform Time (%)*
IPTC	25	11.74
RTA	30	13.07
SEPTA	44	28.37
Average	33	17.73

On average, the case study systems added another 18 percent of a platform hour for absences. The time lost because of absences and the resulting costs added approximately 10 min more of pay for every hour of platform service.

Unlike the largest work rule categories, the absence categories were significant at all three systems in terms of both hours and costs. The five largest categories, ranked by the average percentage of platform time, are presented in Table 2.

Vacations, holidays, and sick leave were the largest categories at all three systems. These categories accounted for most of the impact of absences on the ratio of pay-hours to platform-hours. The effects of injury on duty and requested days off were not identified separately at IPTC and RTA.

The three case study systems reported varying provisions for absences. At IPTC and SEPTA, sick leave is unpaid for the first few consecutive days of absence and paid thereafter. All sick leave at RTA is unpaid. The amounts in Table 2 include the combined effect of paid and unpaid sick leave.

Fringe Benefits

Fringe benefits typically are described in terms of premium cost or dollars of contribution. The ratio of pay-hours to platform-hours uses units of time as its input; therefore, the costs of the benefits were converted into hour equivalents by dividing the fringe benefit cost by the average operator wage

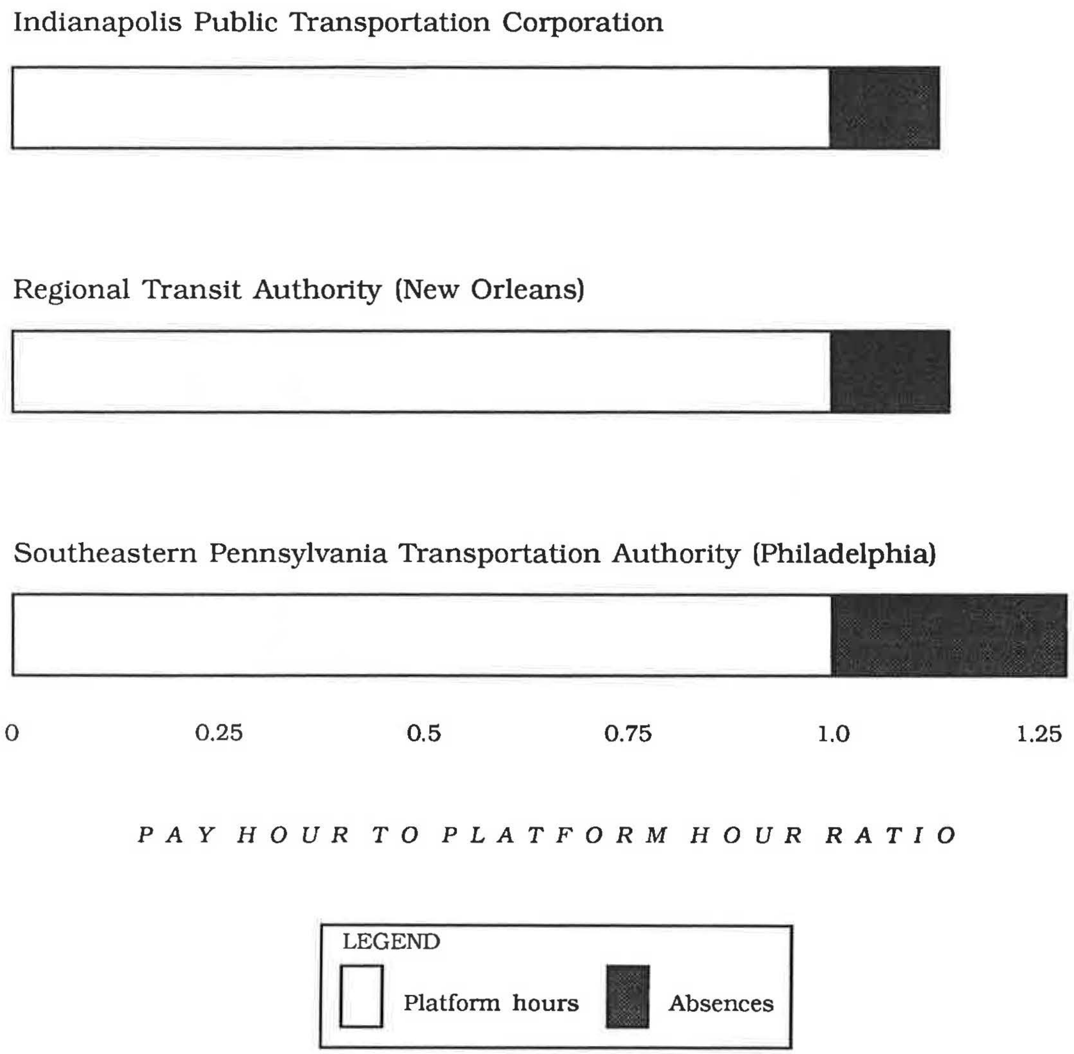

FIGURE 3 Effect of absences on the ratio of pay-hours to platform-hours.

TABLE 2 RANKING OF ABSENCE CATEGORIES

	Percentage of Platform Time			
Five Largest Categories	IPTC	RTA	SEPTA	Average
Vacations	6.52	7.34	9.47	7.78
Holidays	2.90	3.73	5.29	3.97
Sick leave	2.09	0.67	6.94	3.23
Injury on duty	N/A	N/A	3.97	1.32
Requested days off	N/A	N/A	1.18	0.39

per hour. The effect of fringe benefits on the ratio of pay hours to platform hours at each system is shown graphically in Figure 4 and summarized as follows:

System	*Fringes as a Percentage of Platform Time (%)*
IPTC	22.35
RTA	26.85
SEPTA	44.23
Average	31.14

On average, the time equivalents of the fringe benefits costs were more than one-third over the base of platform-hours. This added 19 min more of pay for every hour of platform time.

The largest fringe benefit categories are also the largest of all types of categories. The five largest fringe benefit categories, ranked by the average percentage of platform time, are presented in Table 3.

The three transit systems provide the same basic benefits package to their employees, although the total costs of the fringe benefits as a percentage of platform time were quite different. Health insurance was the largest fringe benefit category at all three systems; retirement was the second largest for all three.

SUMMARY AND CONCLUSIONS

The significant findings from the literature review were documented, the process used to conduct the study was discussed, and the most significant results were summarized.

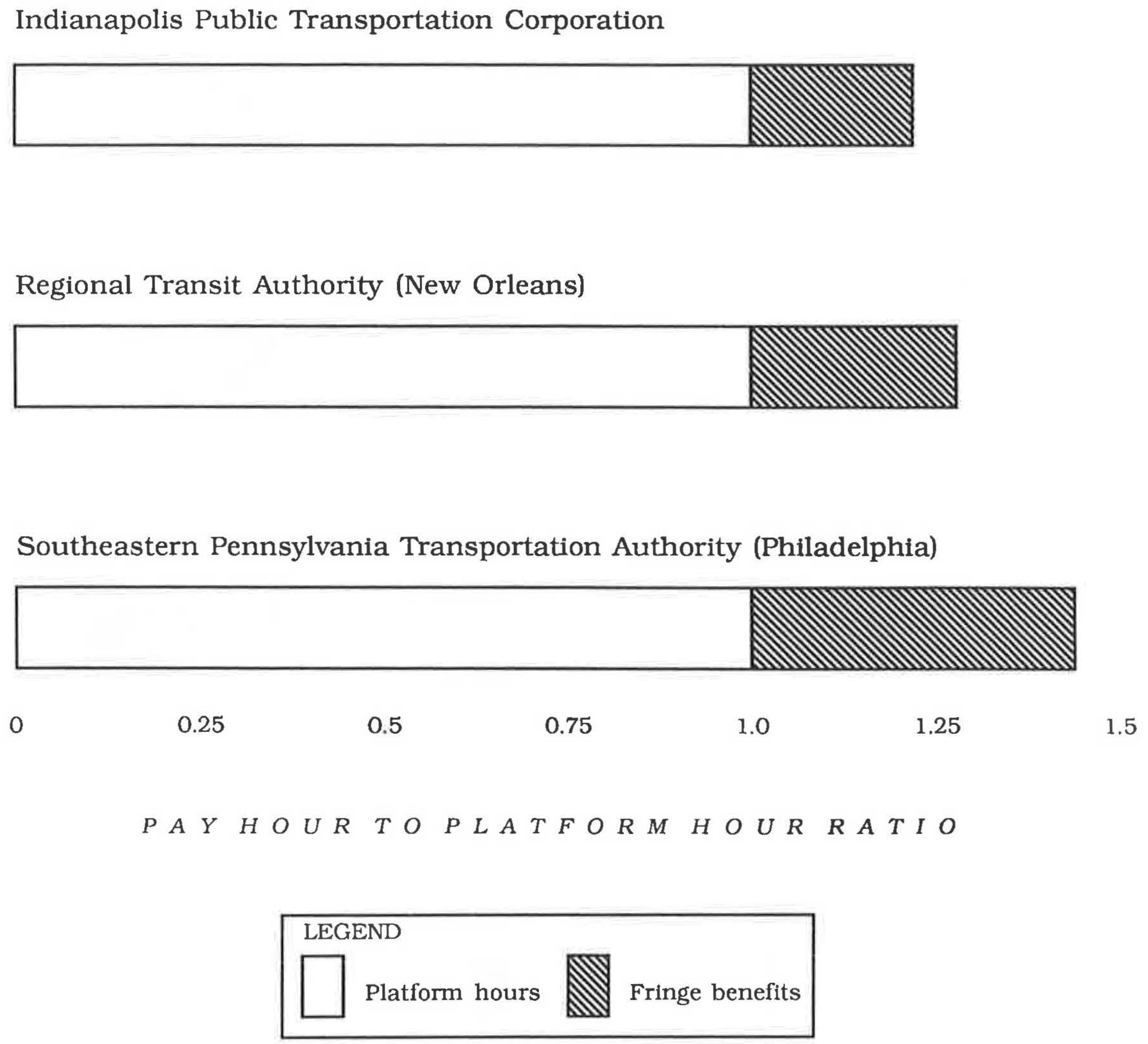

FIGURE 4 Effect of fringe benefits on the ratio of pay-hours to platform-hours.

TABLE 3 RANKING OF FRINGE BENEFIT CATEGORIES

	Percentage of Platform Time			
Five Largest Categories	IPTC	RTA	SEPTA	Average
Health insurance	9.93	12.19	17.59	13.24
Retirement	8.79	7.45	13.19	9.81
Worker's compensation	0.73	1.35	6.01	2.70
Dental insurance	1.56	1.00	1.65	1.40
Free transportation	N/A	N/A	3.96	1.32

Summary

Case studies were conducted to determine the effects of three types of contract provisions (work rules, absences, and fringe benefits) on the ratio of pay-hours to platform-hours. These effects are shown graphically in Figure 5 and summarized as follows:

- Work rules represented a range from 19.50 percent of the platform time at RTA to 38.89 percent at IPTC. The average was 30.74 percent. On average, the largest categories were spread time and overtime premiums, both scheduled and unscheduled.
- Absences represented a range from 11.79 percent of the platform time at IPTC to 28.37 percent at SEPTA. The average was 17.73 percent. The largest categories uniformly were vacations, holidays, and sick leave.
- Fringe benefits represented a range from 22.35 percent (IPTC) to 44.23 percent (SEPTA) of the platform time. The average was 31.14 percent. The largest categories were health insurance, retirement, and worker's compensation.

The largest categories across all of the components (work rules, absences, and fringe benefits) were health insurance, retirement, and vacations. These three categories alone represented over 25 percent of the platform time at each of the three systems.

The sum of all contract provisions represented a range from 59.42 percent of the platform time at RTA to 106.42 percent at SEPTA. The average was 79.61 percent. This average comprised the following building blocks:

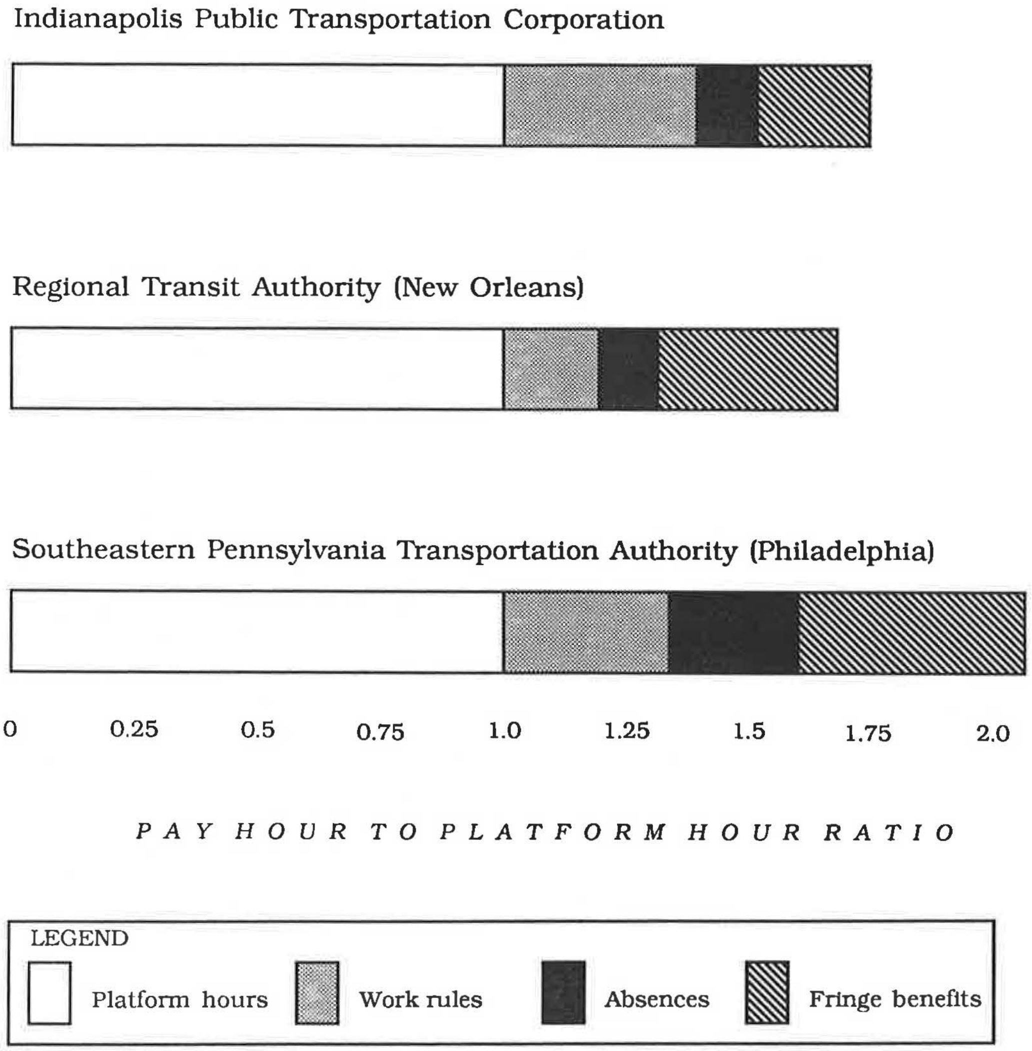

FIGURE 5 Comparison of cumulative effects of labor contract provisions on the operator ratio of pay-hours to platform-hours.

Component	*Percentage of Platform Time (%)*	*Additional Time (min)*
Work rules	31	18
Absences	18	10
Fringe benefits	31	19
Total	80	47

These contract provisions mean that, on average, a system must pay for 1 hr 47 min to get 1 hr of service. The range across the three case study systems was from 1 hr 36 min to 2 hr 4 min.

Conclusions

In this research project, the ratio of pay hours to platform hours was used to quantify the cumulative effect of labor contract provisions on transit productivity. The three case studies yielded information on the extent to which different contract provisions affect this ratio. The three data points provided by these three cases were insufficient for projecting the potential industrywide impacts of labor contract provisions. However, they did permit several key conclusions regarding the research approach.

The effort demonstrated the importance of considering the three components of labor contract provisions simultaneously. Focusing on one element does not measure the overall productivity impact accurately. However, the ratio of pay-hours to platform-hours is typically calculated with only the effect of work rules. Hence, there is a wide discrepancy between the way this ratio is used and the way it should be used.

Transit systems should gather and evaluate the types of information shown in these case studies. This procedure would provide an important measure of labor productivity over time. Further, when cost reduction and productivity improvement strategies are developed locally, they should encompass all components of the labor contract provisions. Productivity improvements will not be achievable unless all three areas are addressed simultaneously. For example, if a system focuses on absences, it may find it has bargained away some fringe benefits that offset any savings in the area of absences. In other words, these programs should produce overall improvements, not just improvements in single areas.

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Scheduling Transit Extraboard Personnel

ISAM KAYSI AND NIGEL H. M. WILSON

Because operators are sometimes absent and daily workloads are often uncertain, transit agencies employ more operators than required by the timetable to ensure reliable service. These extra operators are usually referred to as extraboard or cover operators because they are used to cover the assignments of absent operators and to provide required, but unscheduled, work. Operators who do not have specific work assignments are told to report for work at specific times of the day to cover work that may be open at those times. A methodology is proposed to deal with the problem of assigning report times to extraboard personnel. The proposed methodology is sensitive to the variability of unanticipated requirements, work rules applying to extraboard personnel, reliability objectives, and availability of regular operators to work overtime in case unanticipated requirements cannot be covered off the extraboard. The methodology is applied to a large bus garage at the Massachusetts Bay Transportation Authority to test the quality of the resulting solution under different work rules. This case study demonstrates the potential of the methodology to produce significant improvements over current practice and to serve as a valuable policy analysis tool.

In order to provide reliable service despite operators' being absent from work and to accommodate uncertainty about the amount of work actually required on a given day, transit agencies employ more operators than required by the timetable. These extra operators are usually referred to as extraboard or cover operators because they are used to cover the assignments of absent operators and to provide required, but unscheduled, work. Although most extraboard operators are directly assigned to fill in for scheduled operators whose absences are known in advance, the remainder are assigned report times at which they must be available to cover work that may be open at that time. A method was developed to assign report times for these extraboard operators; the value of the method is demonstrated through a case study of a single large bus garage at the MBTA.

In the transit industry, the issue of operator workforce planning has been receiving increased attention in the past decade, primarily because of the prospects of cost savings through improved operator management methods. Although some of these efforts have focused on the staffing levels required, and hence on the size of the extraboard, little has been reported in terms of analytical methods for assigning report times to extraboard operators who have no specific, known-in-advance work assignments.

MacDorman and MacDorman (*1*) presented the first effort at analytically determining the extraboard size by identifying the major cost factors influencing it. MacDorman (*2*) more directly addressed issues relating to stand-by, or report, operators. MacDorman (*2*) discussed the real-time assignment of stand-by operators to fill open work that was not anticipated. He concluded that fitting manpower levels to the dynamics of open work was of utmost importance. The study also categorized open work, evaluated stand-by operator distribution strategies, and emphasized the importance of considering the complete range and variation of manpower demand.

Booz-Allen & Hamilton (*3*) targeted operator availability management and presented a number of related case studies. However, the issue of assigning report extraboard operators was only mentioned briefly in such general statements as "daily dispatching is responsible for report crew assignment" and "early report operators are split if they receive no assignment." For most, if not all, transit agencies, report operator assignment is based on agency experience without reference to analytical tools.

Koutsopoulos (*4*) and Koutsopoulos and Wilson (*5*) presented a general framework for addressing workforce planning issues at three levels: strategic, tactical, and operational. At the operational level, which is central, the available extraboard personnel are assigned specific times for report duty. These two works form the basis for the methodology presented here.

PROBLEM DESCRIPTION

One of the key tasks of the operator workforce planning process is the management of available operators. In the context of the extraboard, this task translates into the assignment of operators to cover open work, which consists of the following three elements:

1. Covering absences—substitution for absent regular operators;
2. Covering extra work—the operation of extra service for unexpected events and the relaying and shifting of vehicles for in-service breakdowns or major delays; and
3. Operating trippers—working known-in-advance short pieces of work that are not built into scheduled runs.

Extraboard operators may also be called on to provide optional extra service when surplus manpower is available. Because such extra service is not required, but is simply offered when the personnel and vehicles are available at low marginal cost, it should not be considered in sizing the extraboard.

One way to look at extraboard tasks is by their predictability. Some requirements may be known well in advance (trippers, for example); others may be known only a day or so in advance; whereas still others may be completely unanticipated (due to sickness, accidents, and breakdowns). Because of this variation in the predictability of open work, extraboard operators are typically assigned work in the following two-step sequence:

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1. Runs are built to cover known-in-advance requirements.
2. The remaining unassigned extraboard operators are assigned report times to cover work that may become open during the day.

The second step, which is the problem to be addressed, involves selecting report times for a given number of extraboard operators so that operator availability best matches expected needs throughout the day. This broad objective can be translated into more precise objectives that are expressed in terms of uncovered open work, unassigned cover, and reliability.

Clearly, the determination of report times should be sensitive to the probable unanticipated requirements (whether caused by absence or extra service) by hour of day, the probable availability of regular employees to work overtime, the number of available (i.e., unassigned) extraboard employees, and the work rules. Consideration of all these issues complicates the problem.

Because the problem of sizing the extraboard is not addressed here, any considerations relating to the differential costs of using part-time, full-time, or overtime personnel to fill extraboard requirements are irrelevant. The usage of a given number of extraboard operators is maximized (or their unproductive time minimized) by assigning them to best match anticipated requirements. Clearly, results obtained from this research are valuable for the subsequent task of extraboard sizing.

PROBLEM FORMULATION

To formulate the report time assignment problem, two components must be considered that describe the state of the system at time of day t, namely, the number of available extraboard operators and the number of open pieces of work (or runs). The number of extraboard operators available at time t is the sum of those operators who are assigned to report at time t and those operators who reported earlier but are still available because of lack of open work before t. Similarly, the number of open runs is the sum of runs that become open at time t and earlier open runs that are not yet covered. It is evident that the state of the system at time t depends on the history of, and interactions between, the two variables. These factors complicate an exact formulation of the problem; therefore, a simplified formulation was developed.

The simplified formulation is based on defining two time-of-day profiles, which are shown in Figure 1. The operator availability profile, denoted by $x_{(t)}$, is a function of the assigned report times and the work rules and gives the total number

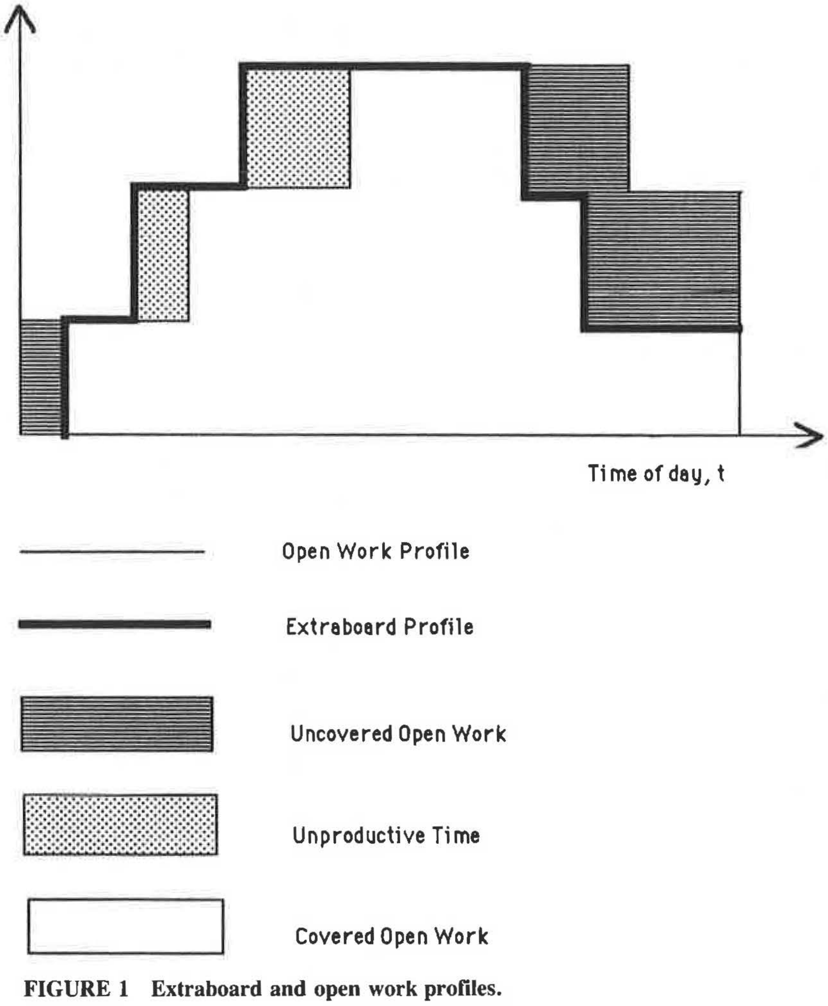

FIGURE 1 Extraboard and open work profiles.

of extraboard operators available at time t. The open work profile, denoted by $\varepsilon_{(t)}$, is the number of open runs that exist at time t. The variable $x_{(t)}$ is a deterministic decision variable, whereas $\varepsilon_{(t)}$ is a random variable in the sense that $\varepsilon_{(t)}$ is known only probabilistically at the time $x_{(t)}$ must be determined.

Using these profiles, expressions can be derived for expected uncovered open work, unproductive time, and system reliability (usually measured by missed trips as a percentage of all scheduled trips). Uncovered open work (UOW) and unproductive time (UT) are also shown in Figure 1 and can be formulated as functions of time t as follows:

$$\text{UOW}_{(t)} = \max\,[0, \varepsilon_{(t)} - x_{(t)}] \tag{1}$$

$$\text{UT}_{(t)} = \max\,[0, x_{(t)} - \varepsilon_{(t)}] \tag{2}$$

As far as system reliability is concerned, any UOW will be split between missed service and overtime in a manner that depends on the availability of regular operators for overtime work. The likelihood that UOW will result in missed service will depend on the time of day at which it occurs; at certain times of day, operators are more likely to be available for overtime work than at other times.

In the following sections, time of day is treated as a discrete rather than a continuous variable. In other words, the day is divided into subperiods, each of which is treated as homogeneous. This simplification of the problem does not entail real sacrifice in the accuracy of the results but makes the solution algorithm computationally more tractable.

Figure 2 shows a model that is used to represent the relationship between UOW and missed service after dividing the operating day into discrete time periods. The model is period-specific and is based on two parameters, $\text{xinter}_{(i)}$ and $\text{slope}_{(i)}$, for period i. If UOW is less than $\text{xinter}_{(i)}$, then all UOW can be worked as overtime. Thus, $\text{xinter}_{(i)}$ represents a lower bound on the overtime hours available during period i. If UOW is greater than $\text{xinter}_{(i)}$, then the surplus will be split between missed service and overtime with the fraction resulting in missed service equal to $\text{slope}_{(i)}$. $\text{Slope}_{(i)}$ can also be viewed as the probability that UOW in excess of $\text{xinter}_{(i)}$ will be translated into missed service. The period-specific parameters $\text{xinter}_{(i)}$ and $\text{slope}_{(i)}$ would reflect the likely availability of operators for overtime work at different times of the day. For example, it is quite likely that no operators will be available for overtime work during the early morning; consequently, $\text{xinter}_{(i)}$ may be set to 0.0 and $\text{slope}_{(i)}$ to 1.0 for these periods. For other periods of the day, however, $\text{slope}_{(i)}$ would depend on the exact time at which open work occurs and the availability of operators willing to work overtime at that time. Consequently, $\text{slope}_{(i)}$ may be less than 1.0.

The proposed model allows the expected missed service hours to be predicted for each period based on the UOW for that period. By summing these missed service hours over all periods of the day, the total expected missed service for that day can be obtained. Moreover, if this measure is used as the objective function in the proposed problem formulation, then a third objective is available, namely, minimization of missed service. Therefore, system reliability can be treated directly as an objective within the proposed methodology, although this requires that both UOW and a basis for splitting it between missed service and overtime (as shown in Figure 2) be available for each period of the day. Alternatively, reliability could be treated as a constraint on the solution rather than as another objective.

To model the possible objectives, expressions are required for UOW (which is closely related to the reliability objective) and UT. It can readily be shown, however, that the objectives of minimizing UOW and minimizing UT are equivalent (*6*). Furthermore, the reliability objective is also a linear transformation of UOW, and any mixed objective related to reliability and overall efficiency can be expressed by appropriate weightings of period-level UOW.

Consequently, the minimization of expected UOW is the central objective adopted in the analysis with the solution subject to work rule constraints. The objective function and the work rule constraints are developed in the following two sections.

OBJECTIVE FUNCTION FORMULATION

By dividing the day into N time periods, the expected UOW can be represented as

$$z = E\left(\sum_{i=1}^{N} \text{UOW}_{(i)} d_{(i)}\right) = \sum_{i=1}^{N} d_{(i)} E(\text{UOW}_{(i)}) \tag{3}$$

Here, $d_{(i)}$ is the length of period i, E stands for the expected value functional, and both $\varepsilon_{(i)}$ and $x_{(i)}$ are assumed constant within period i.

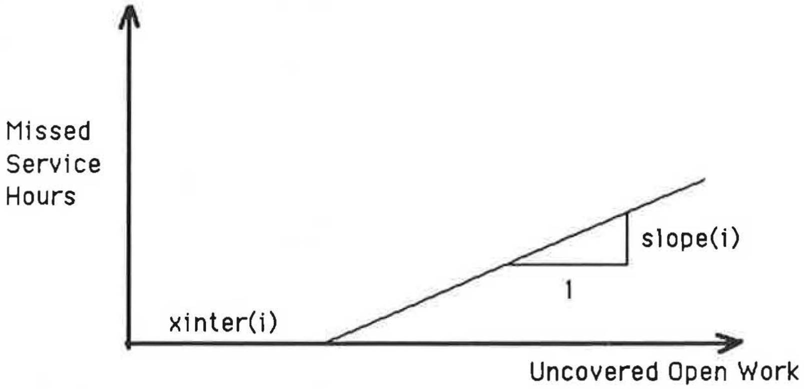

FIGURE 2 Missed service relationship.

Now, $\text{UOW}_{(i)}$ is a function of $\varepsilon_{(i)}$ and $x_{(i)}$ in each period as follows:

$$\text{UOW}_{(i)} = \begin{cases} 0 & \text{when } x_{(i)} \geq \varepsilon_{(i)} \\ \varepsilon_{(i)} - x_{(i)} & \text{when } x_{(i)} < \varepsilon_{(i)} \end{cases} \tag{4}$$

Consequently, the expected value of $\text{UOW}_{(i)}$ becomes the following (dropping the subscript i for the moment):

$$\begin{aligned} E(\text{UOW}) &= \sum_{x}^{\infty} (\varepsilon - x)P(\varepsilon) = \sum_{x}^{\infty} \varepsilon P(\varepsilon) - x \sum_{x}^{\infty} P(\varepsilon) \\ &= E(\varepsilon) - \sum_{0}^{x} \varepsilon P(\varepsilon) - x \sum_{x}^{\infty} P(\varepsilon) \end{aligned} \tag{5}$$

The next critical step is defining the function $P(\varepsilon_{(i)})$, which describes the open run probability density function for each time period i. Open run probabilities in successive periods may not be independent; a run that is open in period i will most likely also be open in period $i + 1$. However, this does not affect the formulation. To define $P(\varepsilon_{(i)})$ is a matter of selecting the discrete probability density function that best describes the occurrence of open work.

Any run scheduled during period i has a probability $p_{(i)}$ of being open and $(1 - p_{(i)})$ of being filled as scheduled. Such an outcome associated with any scheduled run is conceptually equivalent to the outcome of a Bernoulli trial. Moreover, period i has $n_{(i)}$ scheduled runs, each with the same probability of being open. These runs constitute a Bernoulli process, which is a series of independent Bernoulli trials. The probability of exactly $\varepsilon_{(i)}$ runs being open out of a total of $n_{(i)}$ independent scheduled runs in period i is given by the following binomial distribution:

$$P(\varepsilon_{(i)}) = \binom{n_{(i)}}{\varepsilon_{(i)}} p_{(i)}^{\varepsilon(i)} (1 - p_{(i)})^{n(i)-\varepsilon(i)}$$

$$\varepsilon_{(i)} = 0, 1, \ldots, n_{(i)} \tag{6}$$

where

$\varepsilon_{(i)}$ = number of open runs in period i;
$p_{(i)}$ = probability of any run being open in period i; and
$n_{(i)}$ = total number of runs in period i, as given by the scheduled operator profile.

The objective function for UOW minimization can then be rewritten as follows:

$$z = \sum_{i=1}^{N} d_{(i)} \left\{ E(\varepsilon_{(i)}) - \sum_{\varepsilon(i)=0}^{x(i)} \varepsilon_{(i)} P(\varepsilon_{(i)}) - x_{(i)} \left[1 - \sum_{\varepsilon(i)=0}^{x(i)} P(\varepsilon_{(i)}) \right] \right\} \tag{7}$$

with the probability of a particular number of open runs given by the binomial distribution of Equation 6.

WORK RULES

The work rules in effect for extraboard personnel both constrain the feasible solutions and place financial penalties on specific types of solutions. Therefore, it is essential to model those constraints accurately. Extraboard operators may be able to perform either continuous or split assignments on the basis of the work rules; consequently, both types of assignments are considered in this formulation. The formulation allows part-time employees to be assigned to the extraboard, which is the more complex case.

In the simpler case of only continuous assignments' being permitted, two sets of constraints are required. First, the total number of extraboard operators available in period i is simply the sum of the full-time and part-time extraboard operator profiles in period i. These profiles are determined by the number of operators who reported at some earlier period k but are still on duty during period i. Second, the sum of extraboard full-time operators (FTOs) and part-time operators (PTOs) reporting at each time period should equal the total FTOs and PTOs to be assigned report times:

$$x_{(i)} = \text{xf}_{(i)} + \text{xp}_{(i)} = \sum_{k \varepsilon \text{If}(i)} \text{yf}(k) + \sum_{k \varepsilon \text{Ip}(i)} \text{yp}_{(k)} \tag{8}$$

$$\sum_{k=1}^{N} \text{yf}(k) = \text{Nf}; \qquad \sum_{k=1}^{N} \text{yp}(k) = \text{Np} \tag{9}$$

where

$x_{(i)}$ = total number of extraboard FTOs and PTOs available in period i;
$\text{xf}_{(i)}$ = full-time extraboard operator profile in period i, representing the number of FTOs who reported at or before period i but are still on duty, according to the work rules;
$\text{xp}_{(i)}$ = extraboard PTO profile in period i;
$\text{yf}_{(i)}$ = extraboard FTOs reporting in period i;
$\text{yp}_{(i)}$ = extraboard PTOs reporting in period i;
$\text{If}_{(i)}$ = set of report times t for which an extraboard FTO who reports at time t is still available at time i;
$\text{Ip}_{(i)}$ = set of report times t for which an extraboard PTO who reports at time t is still available at time i;
Nf = number of extraboard FTOs to be assigned report times; and
Np = number of extraboard PTOs to be assigned report times.

In some transit authorities, work rules permit management to make split shift extraboard assignments, which consist of two piece assignments with an unpaid break in between. This flexibility provides a greater potential to cover both peak periods with a single cover operator. Alternatively, if an operator who is assigned an early report time is not used, that operator might be released and asked to report later in the day. In this case, within a defined period following the operator's first report, the garage manager has the option to excuse the operator and assign a later report time if the operator has not yet been assigned work. The latest time at which a new report time can be assigned is known as the "decision point." Moreover, there is a spread premium when the total time from the time of first report to the end of the second piece exceeds a certain amount, typically 10½ or 11 hr.

With split assignments resulting from these rules, the operator profile is not fully determined by the first report time, unlike continuous assignments. In fact, the operator profile is not deterministic but depends on whether or not each report operator is assigned a run between the time of first report and the decision point. This assignment depends on the occurrence of an open run during this time span, which in turn depends on the number of bus pullouts and reliefs and the probability of an individual piece's becoming open during each period. As a result, the operator profile is stochastic based on the probability of each report operator being excused at the decision point and assigned a later report time or being assigned work before the decision point.

Although there are many possible work rules, it is assumed that a report operator who is assigned work before the decision point will work a continuous assignment. Moreover, the output of the proposed model includes a first and a second report time for each report operator, with the second report time's going into effect only if the operator is excused at the decision point. Finally, the first and second report times for each operator are assigned in such a way that the total spread is restricted so that no spread premiums are incurred.

Each report operator j will work either a straight shift, determined by the first report (with a probability $pc_{(j)}$ of being assigned a run before the decision point), or a split shift, determined by the first report time, the decision point, and the second report time (with a probability $1 - pc_{(j)}$). Clearly, $pc_{(j)}$ will depend on the first report time and on the report times for other extraboard operators. That is, $pc_{(j)}$ will be a function of the number of bus pullouts and reliefs, the probability of any of these pullouts being open, and the availability of other report operators for the time span extending from the first report time to the decision point.

Consequently, the previous constraint set used for continuous assignments must be modified in the case of split assignments with the following redefinitions of $xf_{(i)}$ and $xp_{(i)}$:

$$xf_{(i)} = \sum_{j=1}^{Nf} pc_{(j)} \cdot rcf_{(ij)} + \sum_{j=1}^{Nf} (1 - pc_{(j)}) \cdot rsf_{(ij)} \tag{10}$$

$$xp_{(i)} = \sum_{l=1}^{Np} pc_{(l)} \cdot rcp_{(il)} + \sum_{l=1}^{Np} (1 - pc_{(l)}) \cdot rsp_{(il)} \tag{11}$$

where

$xf_{(i)}$ = extraboard FTO profile in period i;
$xp_{(i)}$ = extraboard PTO profile in period i;
$rcf_{(ij)}$ = 1 if continuous shift of FTO j includes period i, 0 otherwise;
$rsf_{(ij)}$ = 1 if split shift of FTO j includes period i, 0 otherwise;
$rcp_{(il)}$ = 1 if continuous shift of PTO l includes period i, 0 otherwise;
$rsp_{(il)}$ = 1 if split shift of PTO l includes period i, 0 otherwise; and
$pc_{(j)}$ = probability that report operator j will be assigned work before the decision point.

SOLUTION ALGORITHM

For even a small number of extraboard operators, many combinations of report times are possible. Because it would be computationally prohibitive to evaluate the expected overtime (or unproductive time) associated with all assignment combinations, another solution algorithm was adopted.

The problem formulation requires that the decision variables (i.e., the number of operators reporting in each time period) be integers. However, because most algorithms to determine optimal integer solutions are computationally inefficient, a greedy heuristic procedure was used to solve the problem. It involved the incremental allocation of the available extraboard operators, with each operator assumed to report at the beginning of a period. At each iteration, the appropriate report time is determined on the basis of maximizing the expected marginal reduction of UOW for the operator being assigned at that iteration, while keeping the previous assignments fixed. This process is repeated until all report operators have been assigned report times. The measure of marginal reduction of UOW for each operator is the total reduction in UOW by assigning i to time period t. By adopting this measure, the algorithm assigns all FTOs first and then assigns any PTOs.

Lower bounds on the optimal solution are particularly useful when a heuristic is being proposed because they can be used to determine an upper bound on the difference between the heuristic solution and the optimal solution. In this case, there are two interesting lower bounds on the solution. One lower bound is provided by the solution to the problem with the integrality constraint relaxed. Another lower bound results from relaxing the work rule constraints so that operator duties are not restricted to shifts of fixed length and may be as short as one period. In effect, this assumes that a total supply of report hours is available equal to the total hours to be worked by report operators. Consequently, the incremental allocation in the solution methodology is based on the available extraboard operator periods (e.g., quarter hours) instead of operator shifts. The result is an "ideal" profile, which can also be a lower bound in estimating the savings that may result from relaxed work rules.

CASE STUDY

The methodology was applied to a large bus garage in the Massachusetts Bay Transportation Authority (MBTA), making use of existing MBTA extraboard work rules and other labor contract provisions. At MBTA, both FTOs on 8-hr shifts and PTOs on 6-hr shifts are assigned to the extraboard, but only straight (continuous) shifts can be worked by all operators. A virtually unique feature of MBTA is that, by law, management has the right to use an unrestricted number of PTOs. In addition, extraboard FTOs and PTOs can cover any open work, regardless of whether it is due to the unavailability of an FTO or a PTO. Another MBTA characteristic is that trippers are not permitted, which eliminates one type of task that extraboard operators are usually required to perform.

The spring 1985 schedule was chosen for the primary application of the methodology because extensive data were available for that period. The weekday profile of regular operators (FTOs and PTOs) by time of day shows the heavy peaking that is characteristic of many large U.S. transit authorities (see Figure 3). The 22-hr operating day was divided into 15-min periods for this analysis. Data describing unexpected absence patterns by time of day for each day of the week

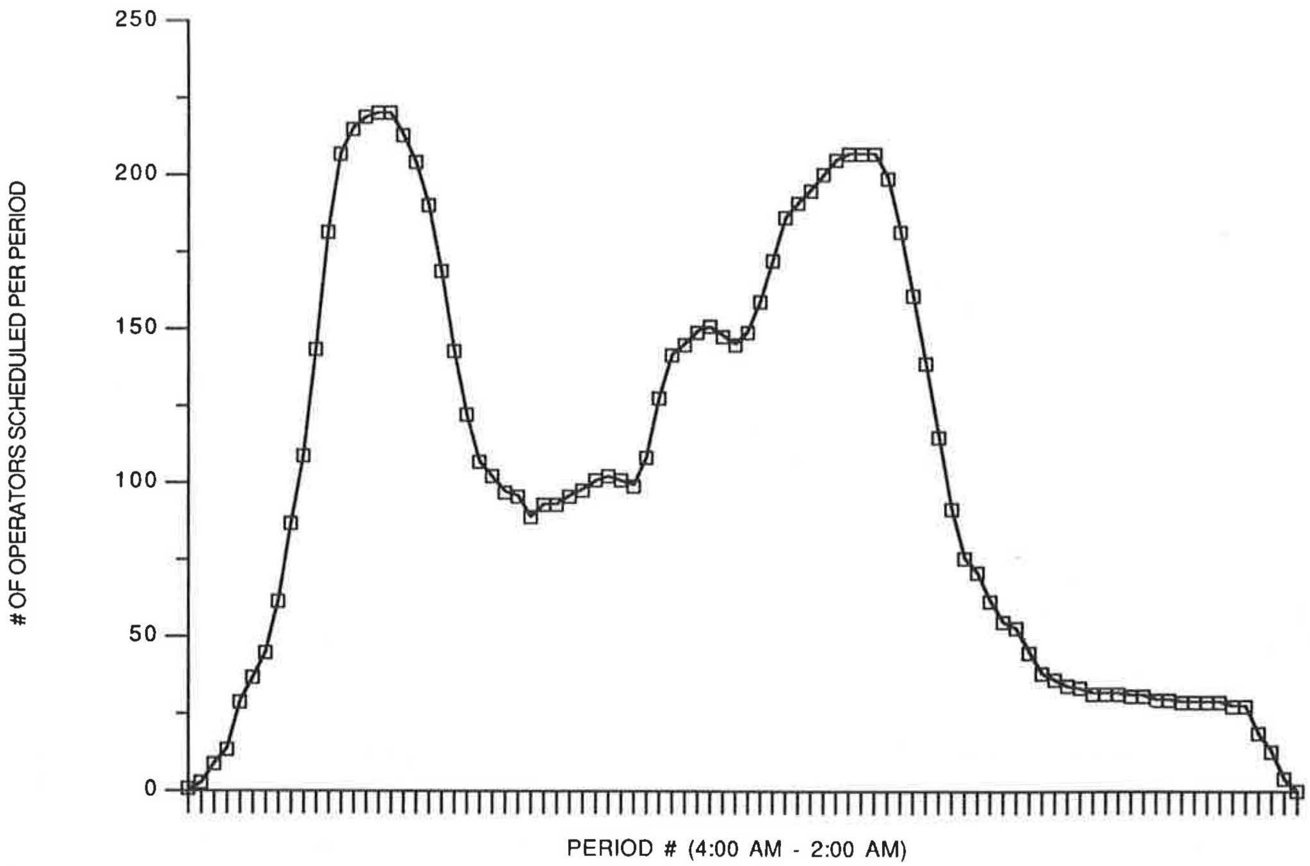

FIGURE 3 Profile of scheduled runs.

were used to determine the probability density functions describing unanticipated requirements by time of day. The number of unexpected absences during each time period was divided by the number of scheduled operators during the same period. This ratio yields the probability of a run being open during that period. By estimating this probability for all periods of the day and smoothing the resulting profile, the open run probability profile was developed for each day of the week. Figure 4 shows the smoothed open run probability profile for a typical Monday.

Unless otherwise stated, the results in this section apply to 10 report operators, 6 full-time and 4 part-time, which was a typical (though not necessarily optimal) weekday level of cover for the selected garage.

Reliability

As described earlier, UOW that occurs in different periods of the day can be split into missed service (MS) and overtime (OT), according to the model shown in Figure 2. This function can be used either to estimate the MS that will occur under the different objectives or to establish minimization of MS itself as an objective. Open work occurring in the early morning (i.e., before 9:00 a.m.) not covered by extraboard operators is unlikely to be filled due to the lack of available operators and their unwillingness to work overtime at that time of the day. Consequently, morning UOW is more likely to result in MS, which will affect service reliability. One way of dealing with this problem is to introduce the morning UOW measure directly into the objective function. Within the framework of the proposed methodology, this can be accomplished by placing a weight, W, in the objective function on UOW occurring before 9:00 a.m. Another way is to define MS minimization as the objective.

Both approaches to reliability were tested for three weekdays (Monday, Tuesday, and Friday), which have different absence patterns. Table 1 presents UOW, morning UOW, MS, OT, and distribution of report hours by time of day resulting from the objectives of minimizing UOW (with $W = 1, 2,$ and 4) and minimizing MS in the proposed methodology. The parameters relating to the split of UOW between MS and OT at different periods of the day were estimated by dividing the operating day into two periods (before and after 9:00 a.m.) and setting parameters in such a way that the overall daily level of MS was the same as that actually experienced at the garage. In the early a.m. period, it was assumed that all UOW would result in missed trips. This procedure was followed because no data relating to the actual split of UOW by time of day were available. However, when data are available, these parameters should be related to the actual split between MS and OT observed during different periods of the day.

As presented in Table 1, $W = 2$ seems to offer a reasonable balance between reductions in morning UOW and increases in total UOW and, in fact, closely approximates the results obtained from minimizing MS directly. Between $W = 1$ and $W = 2$, the increase in total UOW is small, whereas the

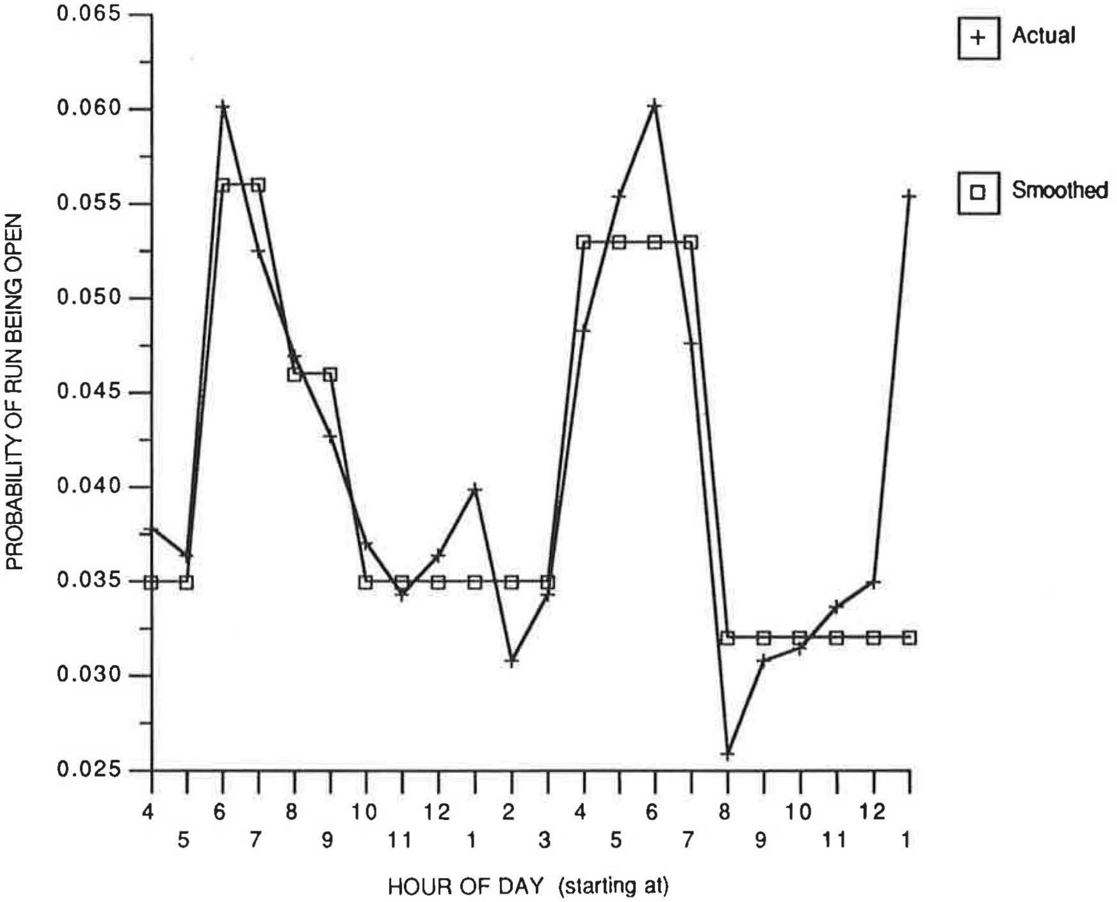

FIGURE 4 Open-run probability profile: Monday.

TABLE 1 SERVICE RELIABILITY

		UOW	Morn UOW	MS	OT	Distribution
Mon	W=1	40.1	14.5	24.1	16.0	28/18/26
	W=2	43.9	9.5	23.7	20.2	39/17/16
	W=4	55.7	4.0	27.2	28.5	55/17/0
	min MS	44.1	9.4	23.7	20.4	40/16/16
Tue	W=1	15.8	3.4	6.7	9.1	27/20/25
	W=2	15.9	3.5	6.8	9.1	27/19/26
	W=4	17.6	2.1	7.0	10.7	34/18/20
	min MS	16.1	3.3	6.7	9.4	28/18/26
Fri	W=1	33.8	9.1	18.2	15.7	21/20/31
	W=2	35.1	6.3	17.5	17.6	27/19/26
	W=4	42.5	2.9	19.9	22.6	38/19/15
	Min MS	35.1	6.3	17.4	17.7	27/19/26

The notation (a/b/c) refers to:

a= hours of morning report time (before 11 AM)

b= hours of mid-day report time (11 AM - 3 PM)

c= hours of PM report time (after 3 PM)

reduction in morning UOW is significant. Between $W = 2$ and $W = 4$, the increase in total UOW is large relative to the reduction in morning UOW. As expected, the distribution of report hours is significantly affected by the value of W, with more reports being shifted into the morning as W increases.

Figure 5 contrasts the occurrence of MS over the course of a Monday between the two cases of minimizing UOW with $W = 1$ and minimizing MS. It is apparent that significantly more MS occurs during the morning peak in the case of $W = 1$ than under the MS minimization objective. However, this situation is reversed during the afternoon. As far as OT is concerned, the $W = 1$ case results in less OT in almost all periods of the day. No OT is required in the early a.m. hours because, according to the UOW split model, all UOW that occurs before 9:00 a.m. is translated into MS. These observations correlate directly with the fact that the MS minimization objective (or the $W = 2$ case) assigns more report operators in the morning hours.

Obviously, the proper W for MBTA will depend on the value MBTA places on avoiding missed trips and its ability to get drivers to work overtime at different times of the day. For this paper, $W = 2$ appears to be a suitable weight for addressing constraints on available OT operators.

Data Issues

The availability of accurate and detailed data may have a significant effect on the outcome of the analysis. Data describing patterns of unanticipated work requirements by day of week and by time of day are critical inputs to the proposed methodology for setting report times. On a day-of-week level, unexpected absence hours, and consequently the probabilities of open runs, varied for the MBTA garage during the spring 1985 schedule. This suggests that different numbers of report personnel are appropriate for different days of the week. Moreover, different report times are likely to be appropriate for each day of the week based on the patterns of unexpected absences for each day. For example, although Monday and Friday have similar overall levels of unexpected absence, the patterns of absence over the course of each day are somewhat different. Because Monday has more morning absences and Friday more afternoon absences, more early a.m. reports should be provided for Mondays than for Fridays.

Analysis that is sensitive to this level of detail in the unexpected absence patterns requires a more extensive data base but is almost guaranteed to produce a better solution in terms of matching resources to needs. This raises the issue of the

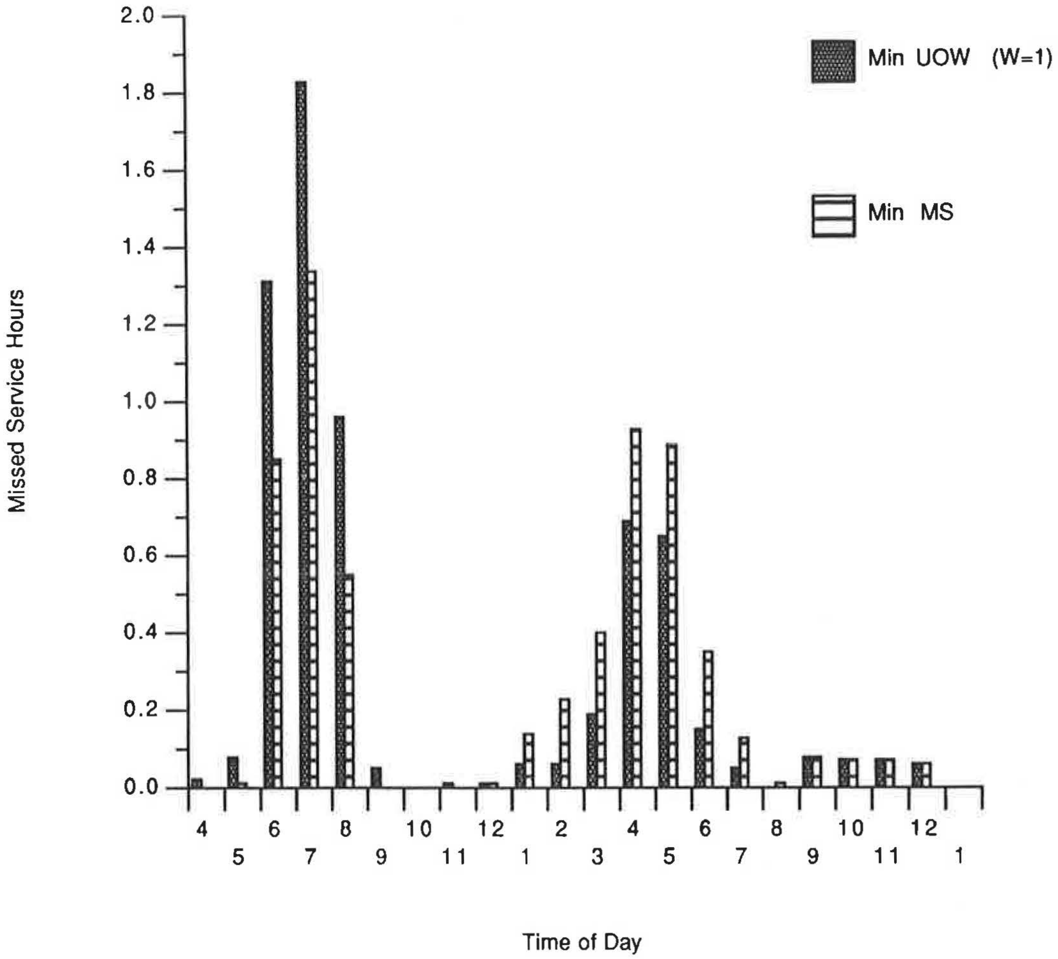

FIGURE 5 Missed service by time of day.

tradeoff between the overhead cost of maintaining and updating a more extensive data base and the cost of the inefficiency introduced into report time setting by using more limited data.

To determine the appropriate level of data, three scenarios were analyzed that feature various assumptions concerning the availability of data on unexpected absences:

1. *Day- and Hour-Specific (DHS).* The open run profiles were set up to differentiate between day of week and time of day assuming full information. This was the basis for comparing the scenarios' performance.
2. *Hour-Specific (HS).* A single open run profile was used for all days of the week that reflected the average patterns of unexpected requirements over the course of a typical day.
3. *Flat (FLAT).* An overall flat rate of unexpected absence was assumed and used to define a single open run profile for all days of the week.

To test the impact of the different levels of data availability, the proposed methodology was used to assign report times under each scenario. Ten report operators (six full-time and four part-time) were assigned report times for a Monday, Tuesday, and Friday for each of the three data scenarios. Obviously, actual levels of report operators to be assigned report times will normally be different for each day of the week based on expected requirements for that day, but such a distinction is not the purpose of this paper. As previously mentioned, a number of planning models exist for optimal sizing of the extraboard and for the daily allocation of extraboard manpower.

Surprisingly, there were no major differences in expected UOW for the three data scenarios (see Table 2), even though the three profiles of open run probability by time of day are somewhat different. The primary differences occur in the distribution of report hours over the day, as evidenced by the (a/b/c) notation. As expected, both the HS and FLAT scenarios are insensitive to differences among days of the week. For example, whereas in Table 2 the DHS solution produces a 39/17/16 distribution for Monday and a 27/18/27 distribution for Friday, the HS and FLAT scenarios produce 27/18/27 and 33/18/21, respectively, for both days. This difference affects the expected morning UOW, as depicted in the same table. For example, the DHS solution yields 9.45 morning UOW hours for Monday, whereas the HS and FLAT solutions yield 14.93 and 12.00 hr, respectively. Therefore, given an equal number of report hours on Monday and Friday, the DHS solution assigns more morning reports on Monday than on Friday as a result of the higher absence levels on Monday mornings.

Figure 6 presents the expected number of open runs on a typical Monday by time of day for each of the three scenarios. This was expected to be a major determinant of the report time assignments. While there are differences among the scenarios in terms of the mean number of open runs, they have the same overall peaking pattern during the day, and it is likely that this pattern, rather than the exact values occurring at the peaks, is the major determinant of report times. In fact, the optimal availability of report operators in the morning hours as determined by the proposed methodology is not much different for the three scenarios, even on Monday.

The similarity of results for the three scenarios on the three days suggests that overall extraboard effectiveness is not significantly increased by additional information although reliability at specific times of day may be affected. However, this conclusion is limited to the case of straight shift assignments and is not expected to be valid in the case of split assignments. For split assignments, the peaks can be covered more efficiently and the peak values, in addition to peaking patterns, are expected to be of significance in report time determination.

TABLE 2 EFFECT OF LEVEL OF DATA AVAILABLE

		DHS	HS	FLAT
Mon	Exp. morn UOW	9.5	14.9	12.0
	Exp. UOW	43.9	40.0	41.1
	Exp. wted UOW	53.3	55.0	53.1
	Distribution	39/17/16	27/18/27	33/18/21
Tue	Exp. morn UOW	3.5	3.4	2.1
	Exp. UOW	15.9	15.8	17.4
	Exp. wted UOW	19.4	19.2	19.4
	Distribution	27/19/26	27/18/27	33/18/21
Fri	Exp. morn UOW	6.3	6.4	4.4
	Exp. UOW	35.1	34.9	37.5
	Exp. wted UOW	41.4	41.3	41.9
	Distribution	27/18/27	27/18/27	33/18/21

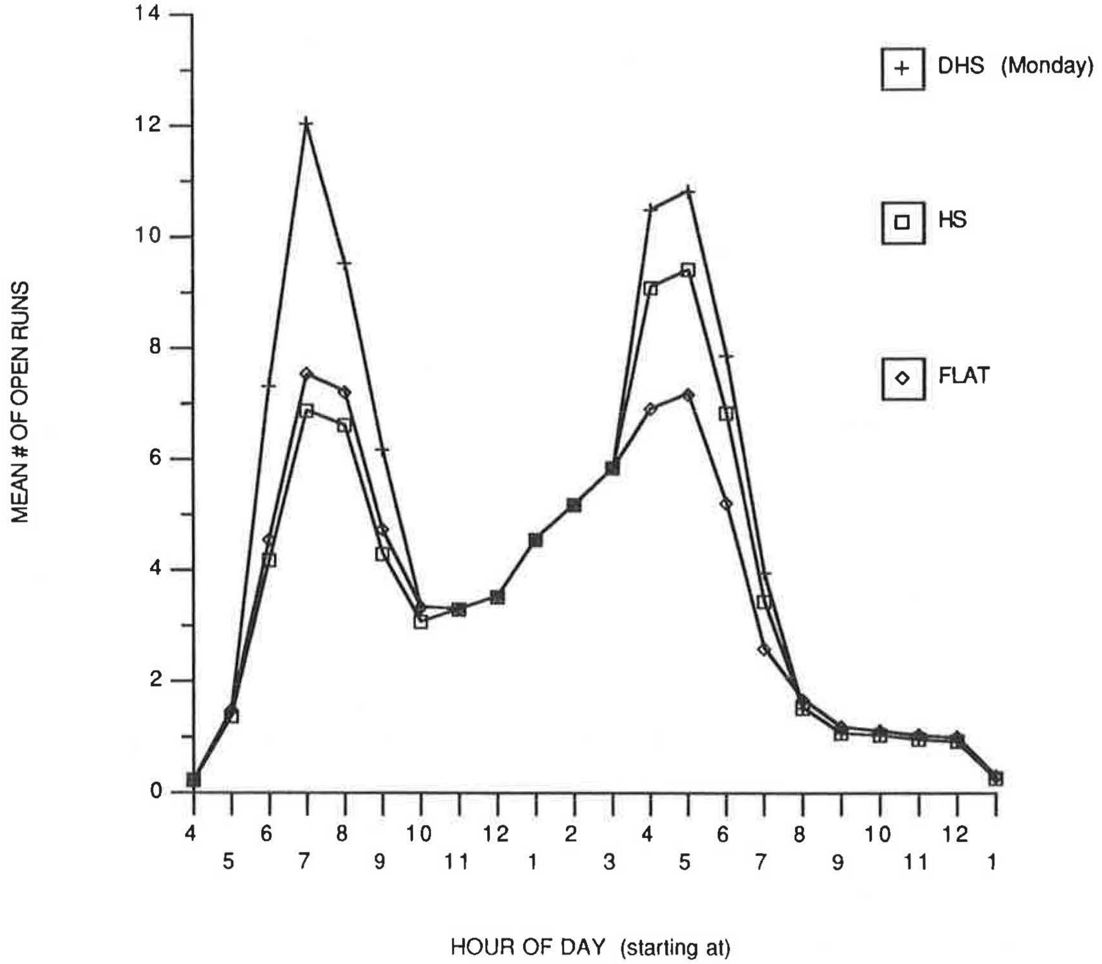

FIGURE 6 Open-run profile.

Lower Bound Results

To evaluate the potential savings from a relaxation of work rules and to assess the effectiveness of the heuristic, a lower bound (LB) was obtained by assigning operator shifts that are not restricted in length. Under this strategy, the allocation of available report time to the different periods of the day yields an ideal profile of report operator assignment. As shown in Table 3, the LB values are from 8.5 to 16.4 percent lower than the model values, after the full 72 report hours are assigned. Because the LB value corresponds to the ideal case of no work rule constraints, it indicates both how far the model results are from the ideal results and how much may be gained from a complete relaxation of the work rules.

Obviously, relaxation of any one work rule would not come close to the "no work rules" scenario; hence, the savings from work rule relaxation will achieve only a fraction of the savings indicated by the LB values. Thus, this lower bound is not very tight and serves only to indicate the general proximity of the model results to the ideal results. This bound is the second lower bound referred to earlier in this paper. It was felt that these results were sufficient to indicate that this method produces close to optimal results and that the alternative lower bound introduced earlier was not necessary in this case.

Evaluating Current Practice

At MBTA, report time setting relies heavily on experience and judgment and little on formal analysis. For this reason, it was expected that introducing analytic tools into the process of setting report times might produce tangible benefits. To evaluate the possible improvements, an experiment was conducted using data from the same MBTA garage during the summer 1987 schedule but relying on unexpected absence patterns developed for spring 1985. The report times actually used at the garage were assessed to estimate the expected UOW if these report times were utilized with the anticipated absence patterns in effect. The expected UOW value was then compared with the values obtained from using the report times produced by the heuristic algorithm.

As shown in Table 4, the methodology, as applied to five consecutive Mondays, consistently outperformed the manual approach used at MBTA. As might be expected, the number of operators actually available for report assignments varies considerably across these days, and so, of course, does the amount of UOW. The expected total UOW or morning UOW levels resulting from the methodology, both for $W = 1$ and $W = 2$, are significantly lower than those expected to occur under the report times actually used. In fact, the $W = 2$ case

TABLE 3 LOWER BOUND RESULTS (HOURS OF UNCOVERED OPEN WORK)

Report	Mon.		Tues.		Fri.	
Hours	Model	LB	Model	LB	Model	LB
0	101.7	101.7	70.4	70.4	96.9	96.9
8	93.7	93.7	62.5	62.4	89.0	88.9
16	86.0	85.7	55.0	54.6	81.2	81.0
24	78.5	77.7	47.9	46.9	73.5	73.0
32	71.4	69.8	41.4	39.7	66.2	65.2
40	64.7	62.1	35.2	33.0	59.2	57.6
48	58.5	54.6	29.8	27.0	52.6	50.2
54	53.3	49.2	25.5	22.9	47.5	45.0
60	48.7	44.0	21.9	19.3	42.5	40.0
66	44.1	39.0	18.5	16.1	37.9	35.3
72	40.1	34.5	15.8	13.2	33.8	31.0
% Diff		14.1		16.4		8.5

TABLE 4 EVALUATING CURRENT PRACTICE

				DHS	
Day	Report Operators (FT-PT)		Act. Rep.	W=1	W=2
Mon 6/29	11-7	morn UOW	6.6	7.2	3.9
		UOW	29.6	19.6	21.9
Mon 7/6	3-0	morn UOW	25.6	26.6	19.9
		UOW	92.5	91.2	92.4
Mon 7/13	6-6	morn UOW	10.8	14.4	9.2
		UOW	53.2	41.6	45.1
Mon 7/20	8-12	morn UOW	4.6	5.4	3.9
		UOW	35.5	16.3	18.1
Mon 7/27	10-5	morn UOW	1.7	9.1	5.4
		UOW	51.4	28.1	31.2

presents a reduction in either morning UOW or total UOW ranging between 15 and 49 percent for each of the Mondays analyzed. Table 5 presents the actual and recommended report times for two Mondays. These results should be viewed with caution because the assumed absence patterns relate to the spring 1985 schedule. It was not possible to base the evaluation on actual summer 1987 absences.

Value of Split Shifts

A final issue to be evaluated in the context of the MBTA case study is the improved efficiency in covering open work that might result from permitting split assignments. Currently, the MBTA work rules only permit continuous assignments for report operators. The following analysis is based on the relax-

TABLE 5 ACTUAL VERSUS RECOMMENDED REPORT TIMES

Mon 7/13		Mon 7/27	
Actual	Recom.	Actual	Recom.
	4.45	4.30	4.30
5.00	5.00	4.30	
	5.30		4.45
	5.45	5.00	
6.00	6.00	5.00	5.00
6.00	6.00	5.00	
	6.00	5.30	5.30
7.00			5.45
7.00		6.00	
7.00		6.00	6.00
7.00		6.00	6.00
8.00		6.00	6.00
8.00		6.00	
	13.30		6.15
	14.00	6.30	
	14.00	8.00	
	14.00	12.00	
	15.30	13.00	
15.45			13.30
18.15			14.00
20.00			14.00
			14.00
			14.45
			15.30

ation of this restriction and on assigning split shifts to report operators according to two rules:

1. A report operator who is not assigned work during the first 2 hr 15 min will be excused and assigned a later report time (defining the decision point).
2. The maximum time allowed from the first report time to the end of the second piece is not to exceed 10 hr 15 min (defining the spread).

This analysis was run for a typical Monday for the same MBTA garage using scheduled run data for fall '87 and assuming 10 full-time and 8 part-time report operators. Table 6 presents values for the slight reductions in UOW and MS achievable by making split assignments instead of continuous assignments. Figure 7 shows the reduction in MS with the incremental allocation of each operator. The slight improvements result from the flexibility afforded by split shifts to match the peaked nature of demand over the course of the day.

CONCLUSIONS

A formulation and solution method were presented for the problem of scheduling a fixed number of operators for report duties at a transit authority. The proposed method incorporates all the important inputs to the problem: the variability of unanticipated work requirements, work rules relating to extraboard personnel and affecting their availability, reliability objectives and constraints, and the availability of regular operators for overtime work. A heuristic algorithm was presented that solves the problem efficiently and is based on the assignment of each operator to maximize the incremental contribution to the objective. The quality of the resulting

TABLE 6 VALUE OF SPLIT SHIFTS TO MBTA

	Oper.	UOW		MS	
		cont.	split	cont.	split
FTO	1	82.2	82.2	47.3	47.3
	2	74.8	74.8	42.1	42.1
	3	68.0	67.5	37.3	37.3
	4	62.0	60.6	33.1	32.8
	5	54.3	54.0	29.3	28.6
	6	49.9	49.1	25.8	24.8
	7	42.9	41.8	22.3	21.1
	8	36.6	36.2	19.2	17.8
	9	32.8	30.0	16.7	14.8
	10	27.3	24.8	14.1	12.1
PTO	11	24.9	21.9	12.0	9.7
	12	20.7	18.1	10.0	8.1
	13	17.3	15.5	8.3	6.3
	14	15.5	12.4	6.8	4.8
	15	12.9	10.6	5.6	3.6
	16	10.3	8.4	4.6	2.8
	17	9.0	6.9	3.5	2.1
	18	7.1	5.2	2.8	1.6
	% Red.		26.8		42.8

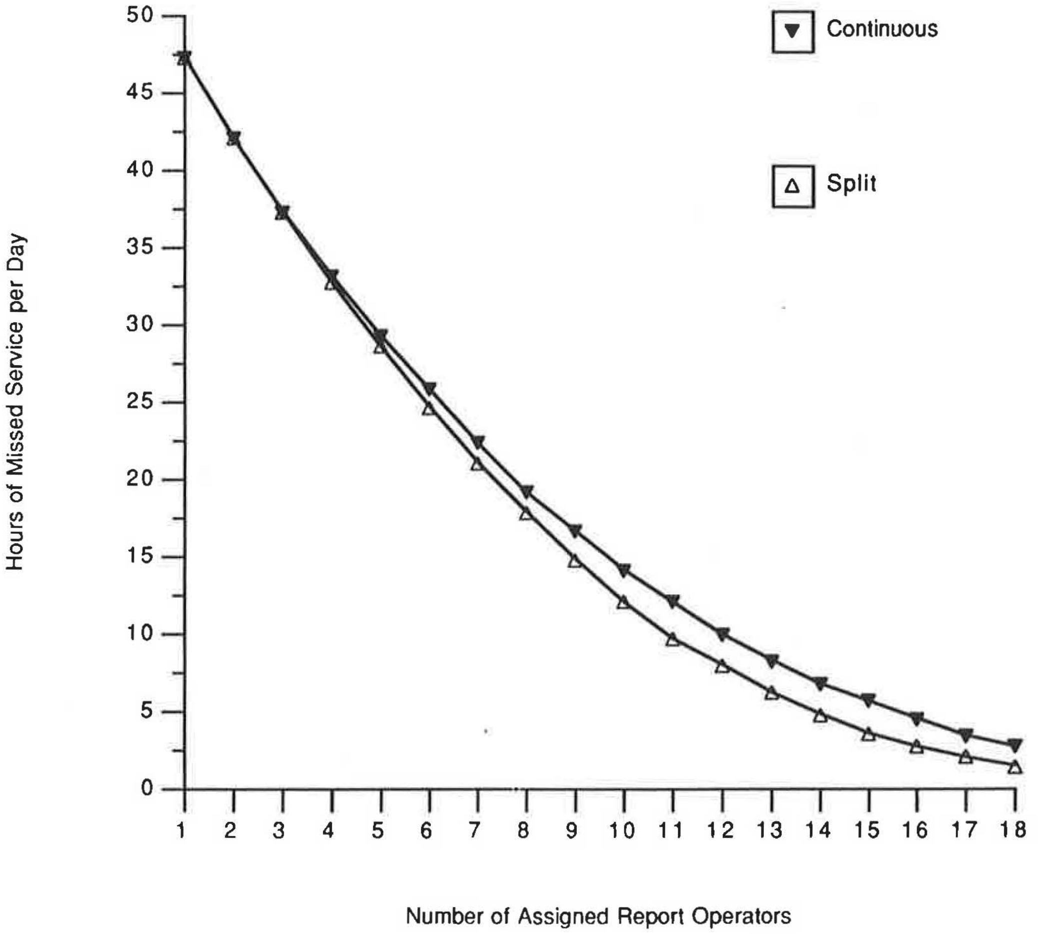

FIGURE 7 Effect of split shifts on missed service.

solution was found to be good when compared with a lower bound to the solution that was also developed within the framework of this study.

The proposed methodology was applied to a case study involving MBTA. The methodology was applied with the objective of minimizing total uncovered open work while meeting system reliability objectives by placing a weight ($W = 2$) in the objective function relating to minimizing uncovered open work on any such work occurring before 9:00 a.m. This produced results that were similar to the case of minimizing missed service for the whole operating day. The case study also indicated that the proposed methodology can be applied based on minimal data requirements (such as a flat rate of unexpected absences) with results offering tangible improvements over current report time setting practices. Other results indicated that small additional benefits can be achieved by having the freedom to assign split shifts to report operators and by having part-time operators work at least some of the report duties. Finally, it was clear from the case study that report time setting based on an analysis of the major inputs to the scheduling problem can offer significant improvements over report times that are based only on experience and common sense. This was evidenced by comparing uncovered open work resulting from report times actually used at the MBTA garage with uncovered open work expected from the implementation of the report times produced by the proposed methodology.

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Drive for Excellence: How To Increase Transit Ridership

RITA BROGAN, HEIDI STAMM, AND JEFF HAMM

Drive for Excellence (DFE), a new concept in employee-based marketing for public transportation, applies to public transportation many of the management principles discussed by Tom Peters in his book *Thriving on Chaos*. The DFE program uses teams of front-line employees, who are given the responsibility and authority (including budget authority) to implement projects aimed at increasing ridership. Implemented at two large agencies to date, the program has proven successful in increasing ridership. It has also been successful in improving employee morale, fostering interdepartmental cooperation, improving customer relations, and enhancing public relations. The structure and implementation of the DFE program, as well as the evaluation methods used to monitor ridership and program performance, are described.

Most transit agencies in the United States would admit to facing a ridership crisis. Decreasing gasoline prices and suburbanization have resulted in increased use of the single-occupancy vehicle and decreased use of public transportation.

As public transportation has lost market share, communities have also lost out through increased traffic congestion and an increased burden on the infrastructure of aging roads. Ironically, the response that many policy-making bodies have taken is to decrease resources for developing and marketing public transportation because of decreasing ridership.

The pressure to increase ridership on public transportation, therefore, has never been greater. Throughout the nation, transit agencies are attempting innovative approaches to increase ridership. The transit industry is being transformed as agencies begin to restructure service, penetrate new market niches, and respond in myriad ways to the changing market demand.

At the same time, businesses in America have been going through a major management revolution, spurred by the teachings of authors such as Peters and Drucker. These authors cite businesses that have succeeded because of their commitment to customer service and the empowerment of their workforces.

The Drive for Excellence (DFE) concept was developed as a program for increased ridership, inspired by the successes achieved in other sectors of the economy through programs that give workers a stake in their companies and some management responsibility for the products they deliver. The program moves beyond the rhetoric of participatory management by giving grass roots teams of employees financial resources, decision-making power, and a strategic framework for increasing transit ridership. The basic concept and history of the DFE program and its potential application to other transit agencies are described in the following sections.

HISTORY

The DFE concept was created at Seattle Metro in 1988 to respond to concerns about decreasing ridership and employee morale. Since that time, the program has been renewed at Seattle Metro and adopted by the Greater Cleveland Regional Transit Authority (RTA).

DFE was structured as a first step in building a new approach to transit management, where everybody in the organization has a responsibility for satisfied customers and increased market share of all public transportation products. There are people within the industry who might argue that the program concept does not take into account the day-to-day realities of transit operations. In both Cleveland and Seattle, the DFE program was developed as a total agency initiative, with strong participation from all quarters of transit operations, including union representatives.

Because of this participation, the DFE program has endured and overcome initial skepticism. The program structure is a simple, decentralized campaign. Teams of employees from each transit operating base are allocated money ($5,000 initially in Seattle and $8,000 in Cleveland) to increase transit ridership. Team members are asked to make their own decisions about activities to increase transit ridership.

Each team is organized by two coaches, who cannot be above a first-line supervisory level. In Seattle, one coach is from an operations division and the other is from a planning or marketing division. Teams can recruit members in any way they choose. The role of midlevel and upper managers is to facilitate and counsel. Overall campaign coordination is provided by a campaign manager, who has day-to-day budget authority for the program.

As noted in the organization chart (Figure 1), teams are supported by planners, who help identify routes with market potential, and by researchers and revenue staff, who monitor ridership (systemwide and on targeted routes) to give teams necessary feedback.

A steering committee made up of senior members of the management team plays a particularly notable role in implementing the management transition that DFE represented. In addition to encouraging communication throughout the organization, the steering committee cuts red tape and encourages flexibility, particularly among midlevel personnel who have much vested in a more structured, hierarchical management system.

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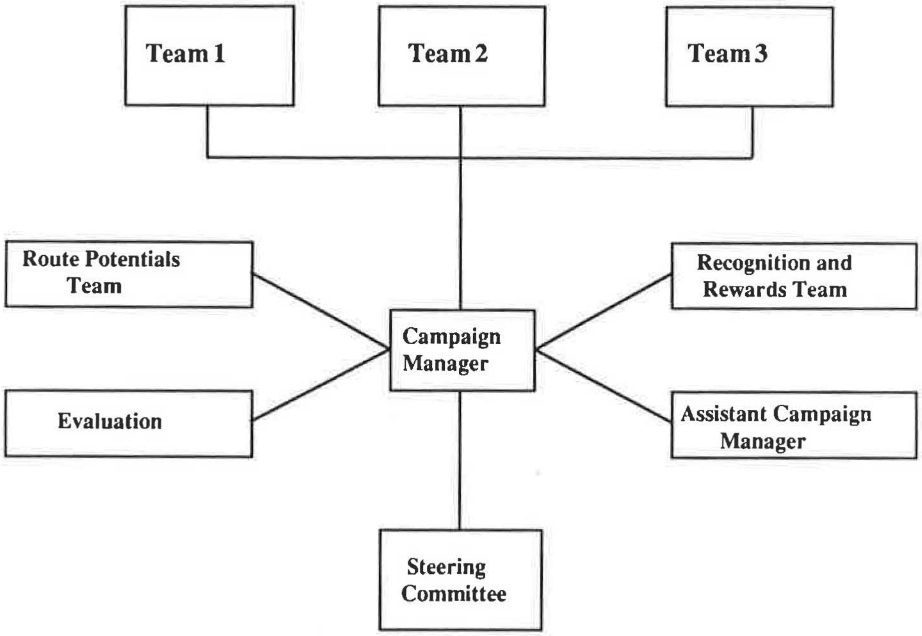

FIGURE 1 DFE organization chart.

The DFE program was a risk, but it was a managed risk. The return on investment has been extremely gratifying to date. In the first few months of operation, DFE teams in both Seattle and Cleveland generated a wealth of ideas to increase ridership and improve public relations. They engaged in projects that ranged from a holiday food drive in Cleveland, which raised over eight tons of canned food, to the creation of a floating bus made of milk cartons, which appeared in a SeaFair festival in Seattle. As the evaluation findings in the next section indicate, the campaigns have helped to attract new riders, improve employee morale, and stimulate positive media coverage.

Both programs are now maturing. Seattle is entering its third year and Cleveland its second. One of the questions that remains is how the DFE concept will evolve over time in a specific location.

EVALUATION FINDINGS

At Seattle Metro, the DFE program went through extensive evaluation in 1988. At the Greater Cleveland RTA, the program has not been in operation long enough for a meaningful evaluation. Therefore, this section includes only the results of the Seattle project.

For management at Seattle Metro, DFE merited scrutiny because it represented a new management approach and a major commitment of staff resources. For the employee work teams, accurate information about the results of their efforts was crucial to sustain motivation and permit the teams to refine and improve their projects.

Therefore, in Seattle, an interdivisional evaluation team was created to assess DFE. Working with management personnel, the team established three main evaluation objectives:

- Test the effectiveness of the campaign in increasing transit ridership and other indicators of campaign progress,
- Identify potential improvements to DFE activities and highlight particularly effective techniques, and
- Record qualitative assessments of the campaign, staff relations, outside interests, media coverage, and other pertinent data.

Special data collection and reporting activities were established. Baseline data on system ridership, as well as ridership on specific routes targeted for improvement by the teams, were established prior to the implementation of campaign activities. Ridership monitors and automatic passenger counters were then deployed in order to collect weekly ridership data on targeted routes. Summary ridership reports were produced periodically and distributed throughout the agency.

The response to promotions was measured by the number of returned free ride tickets from each event. Questionnaires were also included in the information packets distributed to households during three of the major route promotions. This information was used to estimate the number of nonriders attracted to the service on a trial basis.

Each team was also asked to fill out a monthly report that described the specific activities carried out by the team, the amount and type of materials distributed, the number of staff participating, and the total volunteer hours contributed.

Results

The five DFE teams in Seattle began activities in the field in June 1988 and continued their work through the end of the year. During this period, the teams designed and implemented over 45 promotions and activities that would not otherwise have occurred at Seattle Metro. The types of activities undertaken by the teams fell into four general categories:

- Route modifications,
- Targeted information distributions,

- Fairs and festivals, and
- Physical modifications to transit vehicles or facilities.

A complete team activities report for June to December 1988 is available from the authors on request.

Route Modifications

In three instances, teams analyzed a particular route and made changes in routing or scheduling to improve convenience and coverage. For example, one team added a bus stop at a regional park to a route that had previously passed by the recreation site. In another case, a team made a minor adjustment to the schedule of a route that allowed it to meet an earlier ferry and save commuters 15 min.

Targeted Information Distributions

These activities were generally aimed at increasing ridership on selected routes. The teams designed special brochures and usually distributed these with free ride tickets to residences in the vicinity of the route. More than 18,000 residents were targeted in this manner. Distributions also took place at park-and-ride lots, on board ferries, on board designated transit routes, and even in the jury room of King County Superior Court.

Fairs and Festivals

Teams participated in 11 events by entering a float in a parade, setting up a display booth, or distributing balloons, general Metro promotional literature, and free ride tickets. In two instances, the teams arranged for special shuttle buses to provide access to the event. The shuttles ran from nearby park-and-ride lots and, in one case, from a ferry terminal.

Physical Modifications to Transit Vehicles or Facilities

Three teams chose to get a promotional message across by making special changes to Metro vehicles and facilities. The most visible of these was the custom painting (by staff and local art students) of a Zoo Bus for a winding route that terminated at the Woodland Park Zoo. The project resulted in considerable media coverage and higher awareness of transit as a transportation option to the zoo. Another team used recycled materials to construct and post signs at transit freeway stations, giving travel time information from that location to major destinations: "Let Metro Do the Driving. Only 8 minutes to Downtown Seattle."

Response to the many promotions, as measured by free ride ticket returns, varied according to the type of promotion and where the complimentary coupon was distributed. Of the over 50,000 free ride tickets distributed by the Seattle teams, approximately 35 percent were returned. Distributions at park-and-ride lots, on board coaches, and among jurors, however, averaged a 60-percent return rate. About 30 percent of the tickets given out at parades and festivals were used. The lowest return rate of 20 percent resulted from door-to-door distribution.

Survey returns from packets distributed in residential areas indicated that, of the respondents who intended to use the free ride tickets, approximately 40 percent of them did not usually ride the bus. By applying this ratio to the actual number of free ride tickets returned from all home end distributions, the evaluation team estimated that 900 nonriders tried the bus because of these DFE activities. This amounted to about 5 percent of the targeted residences and represented a respectable return rate for mass-mailing-type promotions.

The turnaround year in ridership for Seattle Metro was 1988. After four years of slowly declining patronage, ridership increased by 3 percent in 1988. The goal of 500,000 additional rides by the end of the year was achieved. Many DFE activities resulted in directly identifiable ridership increases. During the summer of 1988, for example, DFE-sponsored special-event shuttle buses carried 7,600 passengers who would not otherwise have ridden.

The teams also targeted 13 existing routes with promotional activities to increase ridership. These routes represented approximately 5 percent of the trips taken on Seattle Metro's transit system. Table 1 shows the annual change in passengers per trip registered on these routes as compared to the rest of the system.

The 12-month analysis indicated that DFE succeeded in raising ridership on the targeted routes at a faster pace than was occurring in the rest of the system. This preliminary conclusion is tempered, however, when the comparison is carried further back. In 10 out of 13 annual signup pairs, beginning with the fall 1983 to fall 1984 period, DFE routes outperformed the rest of the system.

Evaluation Conclusions

The conclusions of the ridership evaluation were

- DFE produced ridership increases that would not otherwise have occurred. This was most clearly demonstrated by those activities that resulted in serviced additions or extensions (for example, special-event shuttles);
- The DFE promotions succeeded in attracting a substantial number of nonriders to try transit; and
- Although ridership increases recorded on DFE routes were higher than for the rest of the system, Metro's systemwide increase in 1988 was the result of other factors as well.

TABLE 1 DRIVE FOR EXCELLENCE RIDERSHIP COMPARISON

Ridership Summary Period by Signup	Percent Change (passengers/trip) DFE Routes	All Other Routes
Spring 1987 to spring 1988	+1.58	+2.98
(Drive for Excellence Begins)		
Summer 1987 to summer 1988	+4.21	+0.36
Fall 1987 to fall 1988	+4.07	+2.97

In more qualitative terms, DFE involved a broad cross-section of staff in a burst of energy to increase ridership. During the campaign, employees, family members, and friends gave more than 3,000 volunteer hours to the effort. The teams also demonstrated a level of cross-divisional teamwork never before experienced in the agency. Employees began to redefine their organizational roles more broadly, demonstrating a better understanding of the interrelated nature of the agency's functions. With a fresh perspective, the teams designed and implemented activities that would not otherwise have happened.

Cynicism, though present, was not pervasive and did not interfere with the spirit or functioning of the teams. As was expected, some friction occurred between teams and regular staff when the teams sought to carry out an activity that affected the responsibility or authority of the regular staff person (for example, minor schedule or route changes). Some activities also proved unproductive and were discontinued. For example, one team bought advertising space in a classified advertising publication and got no response back. Free ride ticket distributions were discontinued at park-and-ride lots when it became clear that the high return rates represented lost revenue more than increased ridership. In all cases, the decisions to initiate or discontinue activities were the responsibility of the team.

THE ELEMENTS OF SUCCESS

Transit agencies considering implementing a DFE program need to incorporate five basic elements into the program's design. They are grass roots participation, leadership and commitment, structure, communication, and feedback and evaluation. Specific issues which Seattle and Cleveland have found problematic in the process of program implementation include middle management commitment, program communication, rewards/recognition, and program continuity.

Grass Roots Participation and Empowerment

The DFE concept cannot succeed without participation throughout the transit organization, especially by front-line employees. Participation in this case means much more than convincing bus drivers to do marketing and promotional work. Rather, it means involvement by front-line employees in every phase of decision making about the campaign, from the planning of activities to allocation of budgetary resources.

In every sense of the word, DFE is owned by the employees who participate in the program. It is very important that all DFE activities be generated through the teams. Teams can consider proposals from outside groups or from transit managers, but it must be their decision to implement the project, even if those activities have never been tried before, or have been tried and failed. Teams need to be allowed to make mistakes. Projects mandated by agency managers are counter to the fundamental principles of the program.

Managers have found their roles somewhat changed in the DFE program. Instead of playing a quality control or disciplinary role, they have been more effective as advocates and facilitators. In fact, the steering committees have been specifically charged to facilitate projects, cut red tape, and address logistical issues in a problem-solving mode.

For both transit agencies, the greatest resistance to participation has come from middle managers, who in some ways have the most vested interest in the bureaucratic status quo. Special guidance must be given to this group, reinforcing the commitment of top management to the program and its goals. In addition, every opportunity must be given to encouraging and rewarding participation by middle managers in this program.

Leadership and Commitment

Some managers have questioned whether front-line staff are ready for the empowerment granted through the DFE program. But perhaps a better question is: Is management ready for the adjustments it must make to allow the program to work? The DFE concept cannot succeed without the commitment and involvement of top agency management. The commitment comes in several forms.

First, a financial commitment needs to be made. Each team needs to have financial resources with which to implement their activities—the amount could be as low as $500 or as high as $10,000, depending on the kind of system. The key is that the teams have some money to work with and that accounting systems are set up to allow them to make decisions about how to spend that money in a timely way.

Second, upper management needs to be prepared to sell the program enthusiastically to middle management, who may resent the potential disruption of the program. The DFE program means taking staff away from some of their day-to-day responsibilities at times. It sometimes means bending the rules to allow more timeliness and flexibility for the program. Agencies unwilling to make that commitment should not attempt to undertake a DFE program.

Third, upper management needs to be involved. They need to be willing to be part of the team process. The DFE structure mandates that senior management meet regularly as part of the campaign steering committee to facilitate elements of the program. The program is enhanced even more when senior management participates in team activities.

Structure

A DFE campaign is structured to allow a free flow of ideas and energy among employees at all levels of the transit department. Seattle Metro and the Greater Cleveland RTA, like many transit agencies across the county, had become internally fragmented. This fragmentation was due in part to geographical separation (bus bases and their personnel located in outlying areas and administrative personnel located in the downtown core). The DFE concept recognizes that teamwork toward a common goal requires that people from different perspectives come together and share those perspectives in developing a strategy for success.

This is often easier said than done, because this philosophy requires that people take a personal risk and join forces with an "unknown quantity." To help break the ice at Seattle Metro, the DFE structure mandates cross-divisional interaction. Team coaches with a planning or marketing orientation are required to choose an advisor from operations divisions. Conversely, team coaches who had their feet firmly planted in the operations side of the house must choose an advisor with a planning or marketing background. Coaches are paired into teams, one from operations and one from planning and marketing. At the Greater Cleveland RTA, the existing organizational structure did not allow the same mix between the planning and marketing and operations staff. Instead, administrative support staff became involved in the program. This structure created opportunities for teamwork that had not before existed at the RTA.

These teams are the heart of the DFE campaign. Each has the basic responsibility of meeting the ridership goal through the activities conceived and implemented by their team members. Team coaches have the responsibility to recruit members, manage the team budget, and monitor team activities. They also have significant responsibility for motivating and rewarding team members for their contributions to the ridership effort. Team advisors are the mentors for team coaches. Their responsibilities include advising coaches on team activity proposals, assisting teams in carrying out their activities, and coordinating with market strategy committee members to advocate for team interest. Team members comprise anyone the team coaches can recruit. It is not unusual for team members to include bus drivers, mechanics, facility maintenance workers, planners, accountants, and analysts.

Much of the success of DFE can be attributed to this unorthodox organizational structure. In addition to DFE's exceeding its ridership goal in Seattle, an interesting phenomenon began to take place. Personnel in all divisions and at all levels of the organization began talking to one another. This talk was not just meeting talk. Instead, it took place in hallways, over the phone, and at lunch. And the talk was not all centered around increasing ridership. Bus drivers wanted to learn about the intricacies of the planning process for a bus route. Marketing people discovered just what it takes for the operations department to respond to a request for a shiny, clean bus to be on display at local events. Supervisors saw that the bright, articulate people who worked for and around them had an untapped well of ideas about running a bus company.

Communication and Feedback

The overall success of the DFE campaign depends upon the many small successes of the individual activities. Over the course of the first year of Seattle Metro's DFE, over 70 activities were undertaken by employee teams, providing many opportunities to talk about individual, team, and campaign successes.

Communication breakdowns usually occur because there is no forum in which communication can take place. Seattle Metro's DFE program guards against this downfall by developing specific communication forums through which to channel DFE news. These forums include newsletters, suggestion boxes, and bulletin boards.

Newsletters

Drive Times, the Drive for Excellence Review and Preview Newsletter was one of the most important communication tools of the campaign. Written by the campaign manager, *Drive Times* was posted at over 100 locations throughout the agency. In keeping with the underlying theme that DFE was a fun activity in which to be involved, *Drive Times* was a chatty, one-page update about team activities, successes measured by the evaluation team, upcoming events employees might want to become involved in, and progress in achieving the ridership goal.

Ideas with Drive

"Ideas with Drive" suggestion boxes were scattered throughout Seattle Metro bus bases and administrative offices. Suggestions were passed along to team coaches, who shared them with team members for their consideration. Employees who submitted ideas were notified as to the status of their ideas and were encouraged to join a team and work to implement the idea.

DFE Bulletin Boards

DFE bulletin boards were installed at all transit department facilities. These bulletin boards were maintained by the team coaches and dedicated to DFE information. Weekly ridership numbers, pictures of team members and team activities, and messages of praise were posted on a continual basis. The DFE campaign manager was responsible for providing coaches with reprints of magazine articles, written information about ridership activities occurring at other transit agencies, and information from the private sector pertaining to marketing or customer service.

Evaluation

A thorough evaluation of a program such as DFE is essential for both management and the staff directly responsible for projects. In Seattle, an interdivisional evaluation team composed of staff with research and analytical capabilities was created to assess DFE. This team first produced an evaluation plan that clearly spelled out objectives, a methodology to gather data, and a schedule of evaluation activities corresponding to the progress of the campaign itself. In addition, each team developed quantifiable nonridership objectives in order to measure the general level of effort and to make sure a team would be credited for completing specific tasks.

CONCLUSIONS

Although the DFE program represents a substantial departure from the standard operations of most transit agencies, it provides a compelling framework for increasing ridership, building interdepartmental cooperation, enhancing employee morale, and improving agency public relations. Agencies considering implementing DFE programs, however, must be prepared to make some major commitments to a very different management philosophy. In addition, consideration must be given to the question, "What next?"

The program at Seattle Metro, just completing its second year, is attracting higher numbers of volunteers. Unless something is done to accommodate the additional workload demands on staff participants, however, the program can be excessively demanding, sometimes leading to burnout. The question remains (at both Greater Cleveland RTA and Seattle Metro) whether DFE will become part of the daily ethic, continue in a campaign mode, or simply be an effective short-term tool for increasing ridership.

These are all legitimate outcomes, but a conscious choice must be made by management to assure their own credibility and the credibility of other employee involvement efforts.

The DFE programs undertaken at Seattle Metro and the Greater Cleveland RTA continue to demonstrate positive results as employees from all levels of the organization are involved in building transit ridership. At both agencies, the consensus is that the benefits have far outweighed the anticipated risks.

The program has proven popular with employees, the community, the media, and elected officials. In addition, management has seen considerable payoffs with greater internal coordination and improved morale. The program and its activities are documented to have increased transit ridership, sometimes fairly dramatically.

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Work Standards: Their Use and Development Using a Maintenance Management Information System

JEFFREY E. PURDY

Work standards are a tool that maintenance managers can apply in annual planning and budgeting, daily planning, scheduling, and work control. Frequently, maintenance managers rely on inherited standards, adapt published standards, or do without. In such cases, they are overlooking a resource, their Maintenance Management Information System (MMIS), which can be used to develop preliminary work standards to aid in planning, scheduling, and controlling maintenance resources. Research for this paper was conducted at a major transit system as part of an overall management study of the organization. A methodology using MMIS records to establish preliminary work standards for division-performed maintenance is presented in the following sections. Preliminary standards for the organization are recommended and the analytical results are interpreted.

The management of maintenance activities and the allocation of maintenance resources to activities represent a long-term challenge to fleet managers. Basic sets of objectives normally underlie the day-to-day management review of maintenance performance, costs, and budgets. Each of these motivators causes managers to examine functions and cost elements in different ways. The typical underlying objectives that motivate maintenance managers are

- The need to manage and control costs (controlling);
- The need to estimate and budget costs with confidence (planning); and
- The need to invest in staff, systems, and facilities to improve service or cost (investing).

The application of work standards in the management of maintenance activities is not frequently encountered in the transit industry. Maintenance managers frequently look for industry guidelines, hoping to discover standards applicable to their fleets. Recent research efforts have provided recommended time standards for hundreds of maintenance activities, as well as methods for establishing time standards (*1,2*).

Earlier emphasis on life-cycle cost vehicle procurements brought forward many of the shortfalls of using repair time standards. However, the life-cycle cost debate did result in the documentation of work standards (*3*). Although the standards proved inconsequential in determining life-cycle cost, because of the dominance of fuel efficiency, many managers recognized the value of standards in controlling, planning, and investing in maintenance activities.

THE ROLE OF STANDARDS IN MAINTENANCE MANAGEMENT

Work standards should be an integral part of the maintenance management process, as shown in Figure 1. The requirements placed on maintenance managers are driven by revenue service vehicle needs, nonrevenue vehicle needs, remanufactured component use rates, and facility needs. These requirements influence both long-range (annual) and short-range (daily and weekly) planning. Daily and weekly planning influences work control at operating divisions and central maintenance facilities. Work control provides the documentation necessary to support special studies to improve reliability, increase efficiency, and improve performance. Maintenance managers should use work standards to fulfill each of these responsibilities. By using work standards in annual planning, daily and weekly planning, work control, and special studies, managers can increase productivity (*4*). Standards are valuable for more than just evaluating employee performance.

Annual Planning

In the annual maintenance planning process, work standards allow managers to determine production plans and rates at both central maintenance facilities and operating facilities. Production plans define resource budgets by determining labor, material, equipment, and facility needs to satisfy production needs. For example, if service requirements, combined with capital and operating cost constraints, call for the rehabilitation of 100 buses per year, then work standards will determine the total labor requirement, in terms of applied labor hours. The required applied labor hours are then converted to staffing levels based on attendance rates, labor agreement terms and conditions, and other factors.

Maintenance resources are finite and must be allocated to achieve high levels of cost-effectiveness. The allocation process balances the use of private enterprise with inhouse capabilities to meet production targets. Work standards in this context can be applied to justify the purchase of maintenance services or the allocation of resources to a maintenance activity.

Daily Planning

Work standards are also an integral part of daily maintenance planning. Without standards, managers may be unable to

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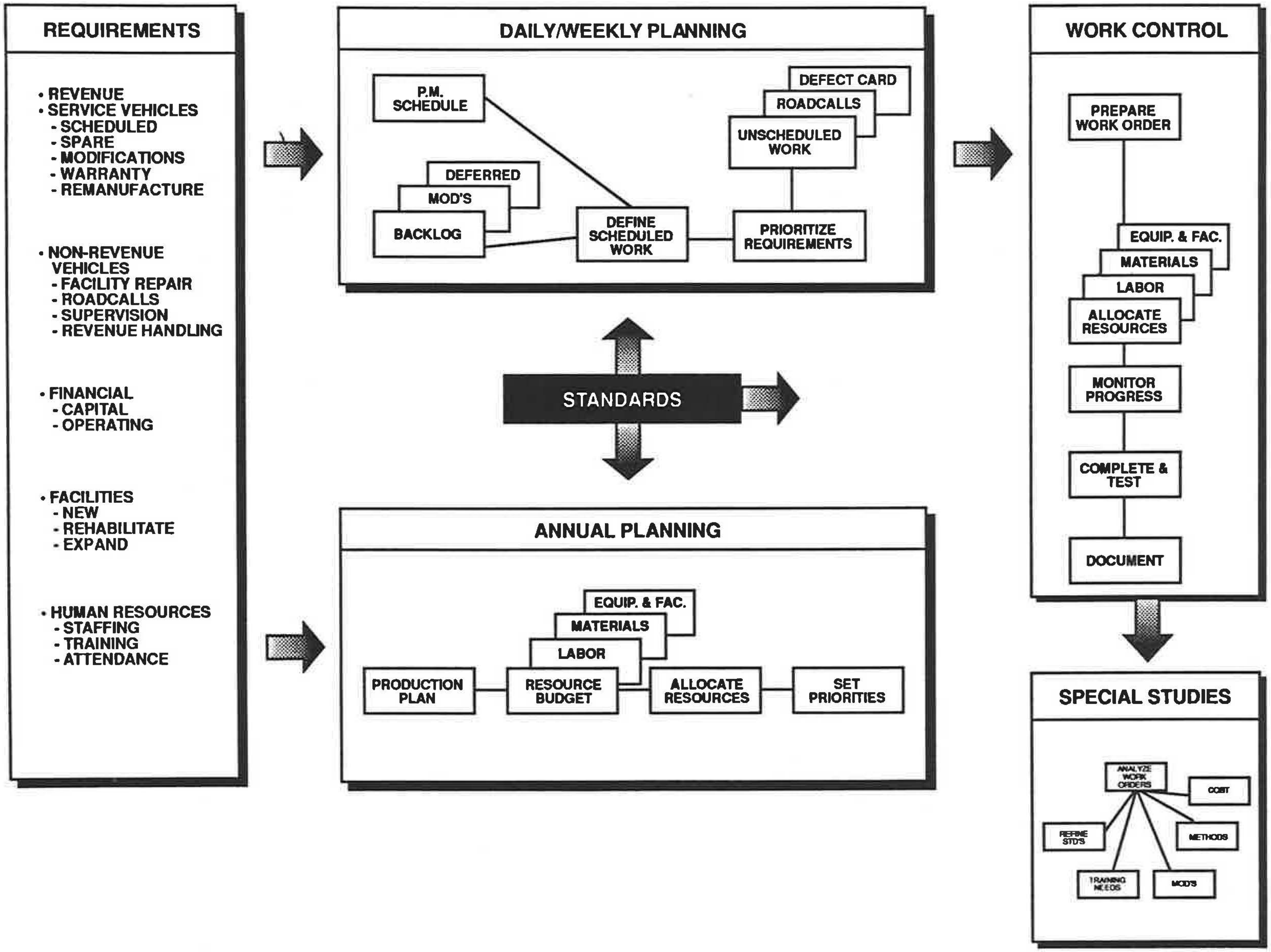


FIGURE 1 Standards influence key aspects of the maintenance process.

maximize workforce use, and overall productivity will decline (5). When this occurs, the unaccounted time (time not reported on work orders or time cards) exceeds expected levels (6). At any maintenance facility, managers must combine preventive maintenance schedules with the maintenance backlog associated with in-service failures, deferred repairs, and vehicle modifications resulting from warranty and engineering studies. Standards define the daily and weekly maintenance demand both for inspection and regular maintenance activities.

Knowing the total maintenance demand, managers make work schedules by balancing preventive maintenance inspections and the repair backlog. Complicating the scheduling process are unscheduled repairs generated by roadcalls and defect cards. Although some transit systems have dedicated roadcall staff, others use shop mechanics on an as-needed basis, resulting in significant disruption to the scheduled work flow. Roadcall resolution is a high-priority maintenance activity, because service disruptions must be minimized.

Defect cards come from two sources. Operators typically complete defect cards at the end of scheduled runs. Operator defect cards must be screened daily by managers to determine the priority of these repairs and to determine resource requirements using work standards. Defects and repair needs are also identified during preventive maintenance inspections. Depending on the work standard used for the inspection, minor defects can be repaired during the inspection. Major repairs, such as brake relines, are typically identified for subsequent repair scheduling.

Work Control

Once a prioritized schedule of work is complete, work orders are assigned to specific maintenance staff, thereby allocating resources to single activities. Work standards can be used to determine which staff members are available for unscheduled repairs. The objective of the manager is to combine assignments to reach the full utilization of staff.

In the example shown in Figure 2, four mechanics are assigned to five repair tasks. Mechanics Smith and Roberts are first assigned to a transmission change (TRN–CHG), which has a work standard of 8 hr with 1.5 staff. To fill Smith's time, a brake reline is assigned, leaving only 30 min of unassigned time. This time can be used for technical problems that may occur in the transmission change, or for unscheduled repairs.

Mechanics Allen and Jones clearly have substantial amounts of unassigned time that can be used for unscheduled repairs. Without using work standards to develop daily work plans, a manager may not be able to determine staff availability for unscheduled repairs or the maintenance backlog.

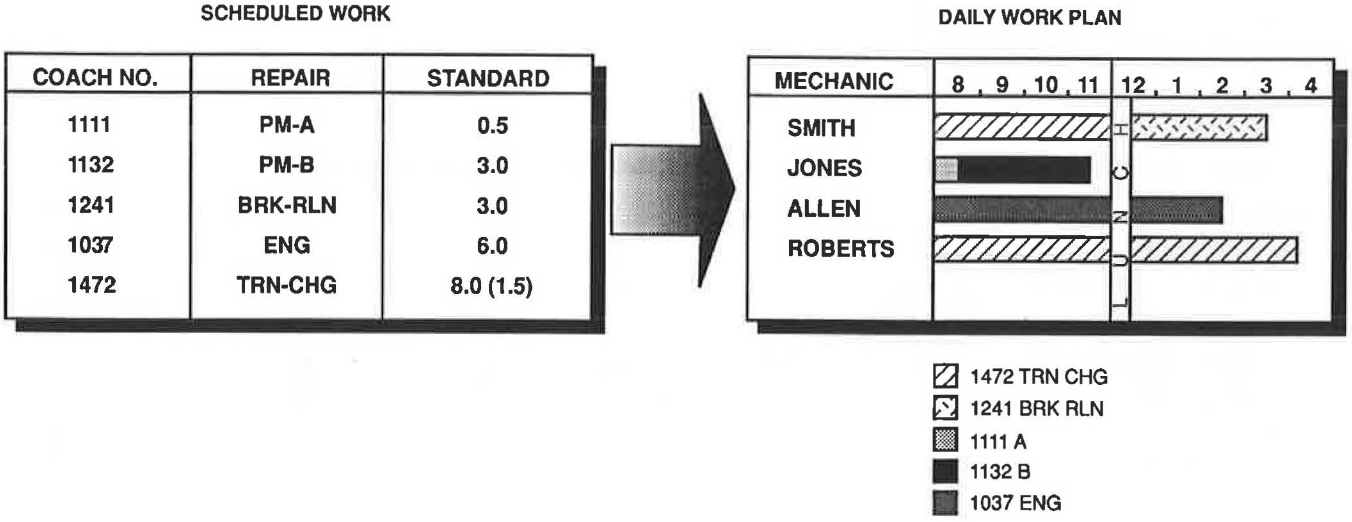
Work standards are also a valuable tool for monitoring repairs in progress. Although work standards reflect typical times for component repairs, repairs generally progress through three phases: troubleshooting and diagnostics, repair and corrective action, and testing.

In the sample daily work plan (Figure 2), mechanic Allen has been assigned to an engine repair. The supervisor should recognize that troubleshooting an engine takes a variable amount of time. However, based on repair experience and the availability of repair time data, the supervisor may know approximately when the diagnostic phase will be complete. Likewise, the supervisor should know the approximate durations of engine repairs and testing. Using informal standards for diagnostics, repair, and testing, a supervisor can review the progress of mechanic Allen to determine whether more or less time (a maintenance resource) is needed for the repair action.

Special Studies

The completion of repairs and their documentation is critical to the ongoing use and evolution of work standards. The implementation of Maintenance Management Information Systems (MMISs) to compile data on maintenance activities provides managers with the information to increase productivity and efficiency (7).

The analysis of work orders can yield valuable information regarding the validity of existing work standards. Significant deviations from established work standards by individual staff



SCHEDULED WORK

COACH NO.	REPAIR	STANDARD
1111	PM-A	0.5
1132	PM-B	3.0
1241	BRK-RLN	3.0
1037	ENG	6.0
1472	TRN-CHG	8.0 (1.5)

FIGURE 2 Application of standards in work planning.

members can indicate training needs. By matching frequencies and times for specific repairs, it is possible to identify component modifications that would improve reliability and reduce repair costs. Likewise, a need for improved methods to reduce repair times, or to narrow the distribution of repair times, can be identified. Finally, combining work standards with cost data to determine typical repair costs or annual repair costs can be used to evaluate the use of private enterprise for specific repairs (*8*).

RESEARCH OBJECTIVE AND APPROACH

Although the value of standards has been demonstrated, some managers have not established work standards or have not recently evaluated current work standards. MMISs contain the resources available to managers to begin developing or revising work standards.

The research effort presented here was part of a management performance evaluation by a major transit operator with a fleet of over 700 vehicles. The objectives of the research were as follows:

- Identify components accounting for significant consumption maintenance of labor resources,
- Develop tools to increase workforce productivity given known staff shortages, and
- Provide guidelines for daily and annual maintenance planning.

Maintenance data were downloaded from the MMIS to compute major component group costs and total annual costs. Repair times per component by activity were also calculated using this data base for component groups with sufficient and reliable data.

To ensure a sufficient number of observations across all repair types, a large sample of work orders was used. Over 42,000 work order entries, covering the period between January and April 1988, were taken from the MMIS to form the data base for the investigation.

To ensure that all data were included for each repair, individual work orders and line items within single work orders were examined. For each unique object code (component) and activity code (repair type) pair, line item labor hours were aggregated to produce a total labor hour data point. The data base was also reviewed for sequential work order numbers with identical object/activity code pairs to screen out multiple work orders for a single repair. The structure of the data base did not allow for the discrete analysis of specific components, such as repair hours for 6V92 engines. Further research, using the methodology provided and including major component identification numbers, would be beneficial. The data required for such an analysis was not included in this data base.

Within the MMIS, maintenance activities were documented using many object codes and activity codes. Object codes describe individual components, subcomponents, and individual parts, whereas activity codes describe the type of repair conducted. The MMIS and its associated work order system use 395 object codes and 17 activity codes for revenue vehicle repairs. This array produces 6,715 object/activity code pairs. Analysis of individual object/activity code pairs would generate relatively meaningless information for managers regarding cost containment, improved work force productivity, and reliability improvement. To effectively manage maintenance resources, managers and supervisors should not be inundated with hundreds of work standards. To be effective, managers use performance guidelines in combination with knowledge of their workforce capabilities and the complexities of maintenance activities.

To identify feasible opportunities for managers to improve maintenance performance, it was necessary to aggregate object codes according to component types or systems, and to aggregate activity codes according to similar types of activities. Object code groups, presented in Table 1, were developed from the object codes currently in the MMIS. A total of 26 object code groups was developed for subsequent analysis.

Activities were also grouped, producing 12 activity codes for analysis, as presented in Table 2. Similar types of MMIS repair activities that were anticipated to have comparable labor hour requirements were grouped together. The aggregated codes provided specific information regarding division and central maintenance performance.

The reorganization of terms could produce up to 312 object/activity code pairs. Although more manageable than 6,715 code pairs, these repair descriptions may still be too numerous for managers to effectively apply as time standards. However, the 26 object codes and 12 activity codes allow managers to understand which components and repairs consume the most labor hours and cost. Repair time distributions were developed by object code, and preliminary work standards were developed for the top 10 components.

PRELIMINARY WORK STANDARDS

The distribution of labor hours across major component groups focuses attention on specific components where more efficient procedures could improve maintenance productivity. The average repair times derived from the investigation can be used to improve the scheduling of planned or unplanned repairs. The methodology and results represent a first step toward establishing work standards. Use of the average repair times can assist in improving workforce utilization, reduce unaccounted time, identify mechanics' performance and training needs, and provide managers with a better understanding of where maintenance resources are applied.

The average repair hour figures provide a preliminary work standard time that can be used in time planning for maintenance activities in the division facilities. The standard deviation provides a measuring device reflecting the range of observed repair times about the average; because of aggregation of both activity codes and object codes, high deviations were expected. For example, different types of engines (such as 6V92 and 8V71) will cause clusters of observations at different time periods. The average repair time would be between the two clusters, and the deviation would include the two clusters.

The inclusion of several activities into a single activity code group was also expected to produce high deviations. For example, inspecting a bad order coach (IBO) should take more time than checking fluids (CHK), yet both activities are within the inspection activity code group.

The broad range of scheduled and unscheduled repairs occurring at the divisions during the analysis period, combined with

TABLE 1 MMIS OBJECT CODE REGROUPING

MMIS Object Code Range	Analysis Object Code Group Description
0100 to 0192	Front Axle
0200 to 0292	Rear Axle
0400 to 0450	Brake System
0500	Clutch
0600 to 0692	Cooling System
0700 to 0783	Electrical System
0800 to 0897	Engine
1100 to 1120	Frame
1200 to 1292	Fuel System
1400 to 1492	Suspension
1600 to 1692	Steering
1700 to 1792	Transmission
1800 to 1892	Drive Train
1900 to 1940	Wheels
2400 to 2437	Body - Exterior
2438 to 2492	Body - Interior
2600 to 2692	Air Conditioning
3000 to 3091	Air Group
3200	Flex Line
3500	Auxiliary Equipment
3540	PA System
5300 to 5301	Destination Signs
5400 to 5401	Farebox
5500 to 5515	Wheelchair Lift
5600 to 5603	Transfer Machine
9000	Preventive Maintenance Inspections

the varying working conditions, further influenced average repair times and deviations. At the time of the research, two maintenance facilities were undergoing significant reconstruction, which disrupted normal repair activities.

Although these factors will produce higher deviations in repair times than figures from a disaggregate analysis, the average times can still be used as a first step and tool for planning and controlling maintenance activities and achieving productivity improvements. To provide this tool, the average times for each phase of a repair (troubleshooting and diagnostics, repair and corrective action, and testing) were combined, resulting in a repair time standard for component repairs. The application of such a preliminary time standard should also incorporate the experience and judgment of individual maintenance supervisors.

Research efforts in transit maintenance have suggested that repair time distributions conform to gamma distributions (*1*). Although the research conducted for this paper did not address this hypothesis, the repair time distribution did resemble a gamma distribution. Further research in this area would be beneficial to further development of repair time standards.

FINDINGS

The distribution of labor hours by major component groups identified 10 groups that accounted for over 85 percent of the labor hours in the divisions, as presented in Table 3. The development of preliminary work standards for these component groups was the focus of the research. The preliminary work standards represent a first step toward providing managers with a tool to increase the control of labor resources. The intent of the research was not to develop absolute standards, but rather to examine repair times for the 10 component groups and establish opportunities for increased productivity. Discussions were conducted with maintenance managers to explain the distribution of repair times and to identify feasible opportunities for productivity improvements.

Preventive Maintenance Inspections

Preventive maintenance inspections account for 28 percent of the labor hours in the divisions, as presented in Table 3.

TABLE 2 MMIS ACTIVITY CODES

MMIS Activity Code	Description	MMIS Activity Code	Description
ADJ	Adjust	OTH	Other
ASM	Assemble	PNT	Prepare and Paint
CHG	Change	RBO	Running B.O.
CHK	Check	RCL	Roadcall
CLN	Clean	REQ	Requisition
CRG	Charge	RFC	Reface
DIS	Disassemble	RLN	Reline
IBO	Inspection B.O.	RMN	Remanufacture
INS	Inspect	RMV	Remove
IST	Install	ROT	Rotate
LUB	Lubricate	RPR	Repair
MAG	Magnaflux	RTQ	Re-Torque
MCH	Machine	SFI	Safety Inspection
MJI	Major Inspection	SOV	Semi-Overhaul
MNI	Minor Inspection	SRV	Service
NOR	Normalize	STM	Steam Clean
TST	Test	WLD	Weld

Reorganization of Activity Codes for Analysis

Inspection = IBO, INS, CHK, TST, CLN, SRV, STM, DIS
Light Repair = ADJ, CRG, ROT, RTQ, LUB
Heavy Repair = RLN, RBO, RPR
Remove-n-Replace = CHG, IST, RMV
Rebuild = MAG, MCH, NOR, ASM, WLD, RFC
Body = PNT, REQ, OTH
Safety Inspection = SFI
Roadcall = RCL
Minor Inspection = MNI
Major Inspection = MJI
Semi-Overhaul = SOV
Remanufacture = RMN

TABLE 3 DIVISION MAINTENANCE LABOR-HOUR DISTRIBUTION OBJECT CODE RANKING BY TOTAL HOURS

Major Component Group	Percent of Total Hours	Cumulative %
1. Preventive Maintenance Inspections	28.0	28.0
2. Electrical System	12.0	40.0
3. Brake System	8.6	48.6
4. Body Exterior	7.5	56.1
5. Wheelchair Lift	6.7	62.8
6. Engine	6.6	69.4
7. Air Group	4.7	74.1
8. Suspension	4.7	78.8
9. Transmission	3.6	82.4
10. Cooling System	3.5	85.9

Within this activity, safety inspections clearly dominate in frequency of occurrence, as shown in Figure 3. However, major inspections account for over half of all inspection labor hours. An examination of the labor hour distribution reveals that

- Safety inspections are typically completed in 0.32 hr.
- The average minor inspection time is 1.28 hr. The small standard deviation reflects the narrow distribution of observed times. Minor inspections account for 19 percent of all inspection hours.
- An average time of 2.98 hr was calculated for major inspections. The distribution of inspection times indicates major inspections' being performed from between 1.5 and 2.0 hr to between 4.0 and 4.5 hr.

Safety inspection work standards of 0.25 hr and minor inspection work standards of 1.25 hr appear to be appropriate and should be vigorously applied by maintenance managers. The performance of major inspections should be closely examined through direct observation to explain the broad distribution of observed times. The appropriateness of a 3-hr standard based on the average inspection time cannot be determined at this time.

Electrical System

Electrical system repairs are a major consumer of maintenance resources from a labor-hour perspective. The distributions of repair times and average repair times shown in Figure 4 begin to explain the high cost of electrical system maintenance.

- Remove-and-replace activities account for over 60 percent of observed electrical system repairs and have an average time of 0.57 hr. However, the distribution is broad (reflected by the high standard deviations), as expected, because of the variety of electrical components included in the consolidated object code.
- Heavy repair activities have an average time of 0.56 hr and a high relative standard deviation. This activity accounts for almost 30 percent of the observed electrical system repair times.
- The average light repair time is 0.33 hr, principally reflecting battery charging and cleaning of battery trays. Light repairs account for less than 5 percent of all electrical system repair hours, therefore representing only limited opportunities for improving maintenance performance.
- Inspection of electrical systems accounts for the fewest number of observations and less than 5 percent of the hours. Given the difficulty of diagnosing electrical system failures, the low frequency of occurrence indicates that not enough troubleshooting is being done. This situation would contribute to the high number of remove-and-replace observations.

The dominance of remove-and-replace and heavy repair activities, accounting for approximately 90 percent of all electrical system repair labor, indicates that significant manage-

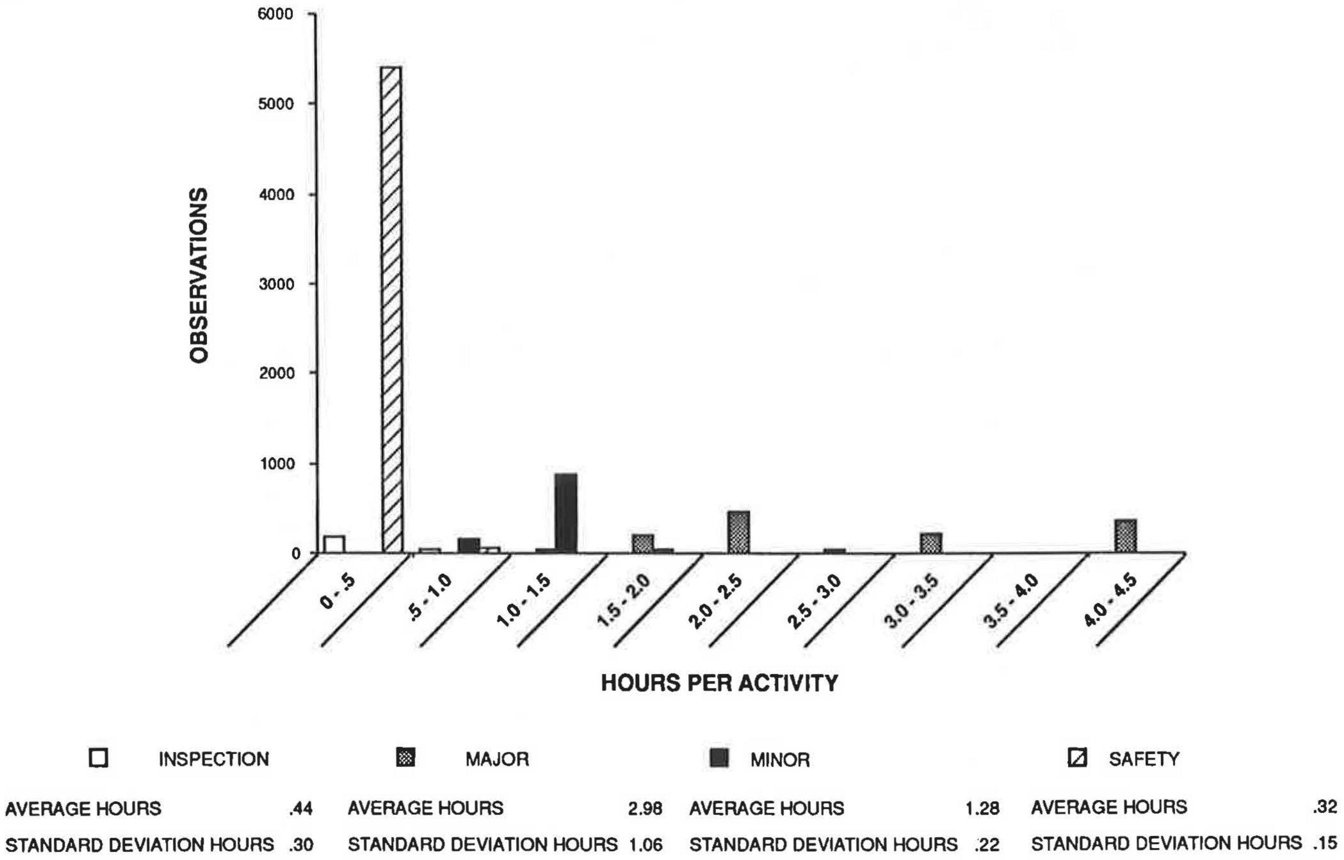


FIGURE 3 Preventive maintenance inspections (Object Code 9000).

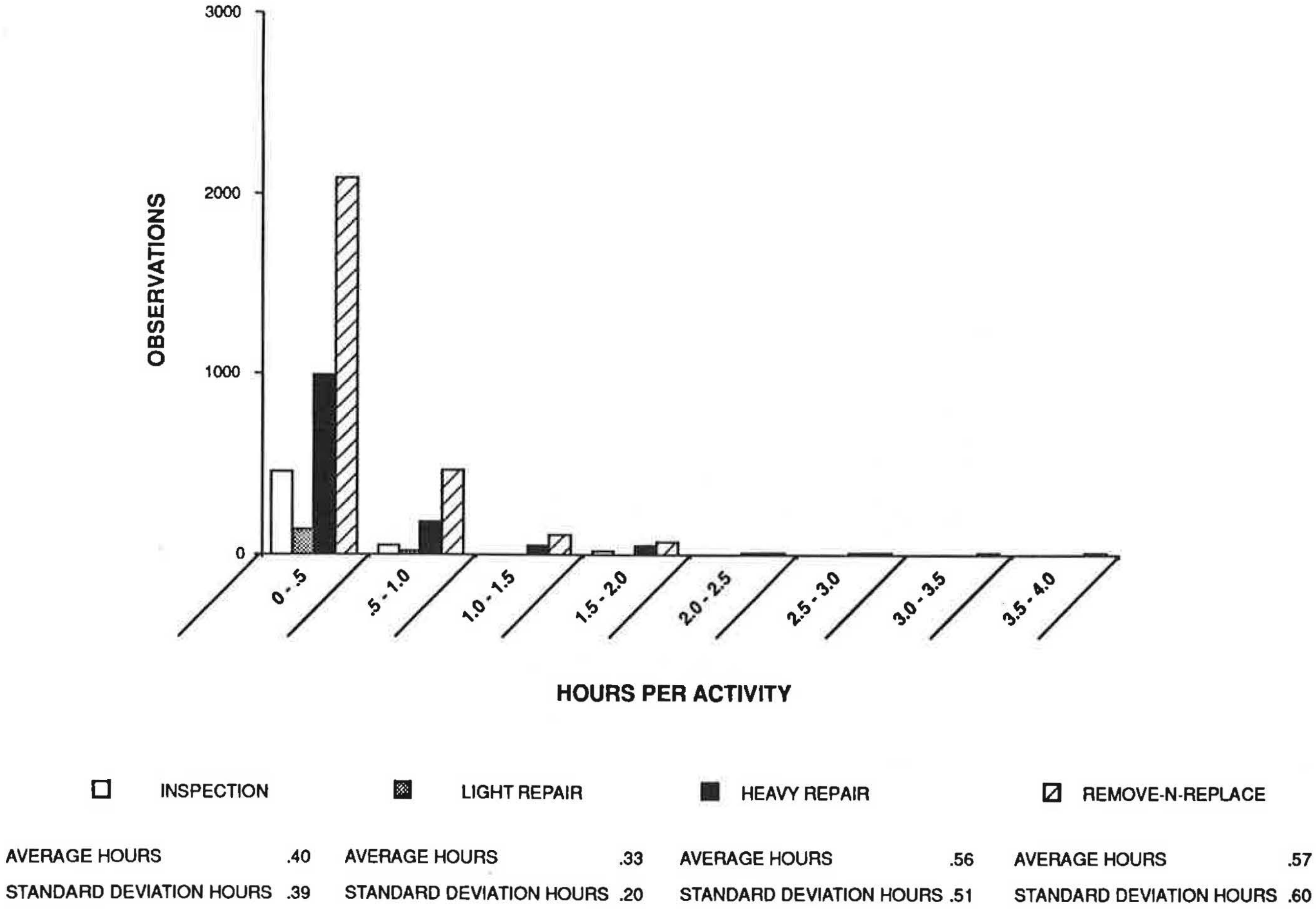


FIGURE 4 Electrical system (Object Codes 0700–0784).

ment and supervisory focus should be placed on this aspect of electrical system repair.

In terms of preliminary work standards, a time of 1 hr should be anticipated for preliminary diagnostics (inspection) and corrective action. A more rigorous standard of 0.5 hr for remove-and-replace activities could be adopted, particularly if a policy is adopted to troubleshoot and repair electrical components at the central maintenance facility. Adopting such a policy would increase the availability of division mechanics and potentially improve the quality of repairs, because skilled electrical mechanics would perform repairs in a more controlled environment.

Brake System

Average brake system repair times, anticipated to be 4 to 5 hr, are noticeably lower at a total of 2.78 hr for remove-and-replace plus heavy repair, as shown in Figure 5.

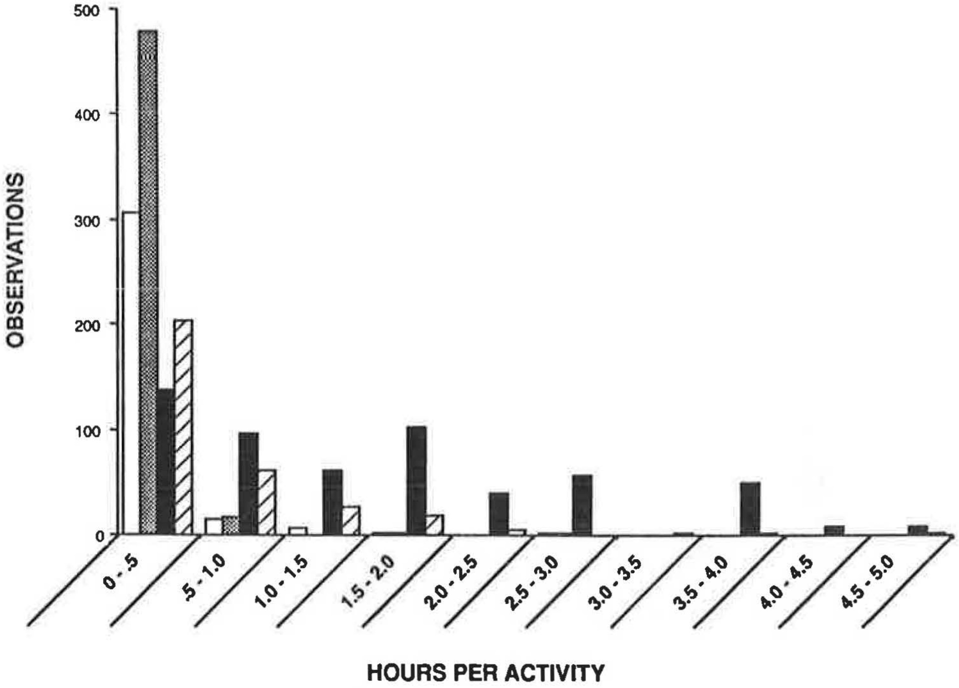
- For heavy repairs, times ranged between 0.25 and 5 hr. The low average time of 1.86 hr coupled with a high standard deviation of 1.39 hr indicates that the average time cannot be used as a preliminary standard.
- The average light repairs time of 0.26 hr plus the average inspection time of 0.36 hr provides a reasonable standard of 40 min for brake adjustment, assuming that both wheels on the same axle are done simultaneously.

The average brake system repair hour findings are influenced by reliability problems with automatic slack adjusters. The reliability of this component is cited by managers throughout the industry as a problem. Slack adjusters are contributing to the broad distribution of heavy repair times. However, they do not completely explain the variation, particularly with the few observations over 4 hr.

Body Exterior

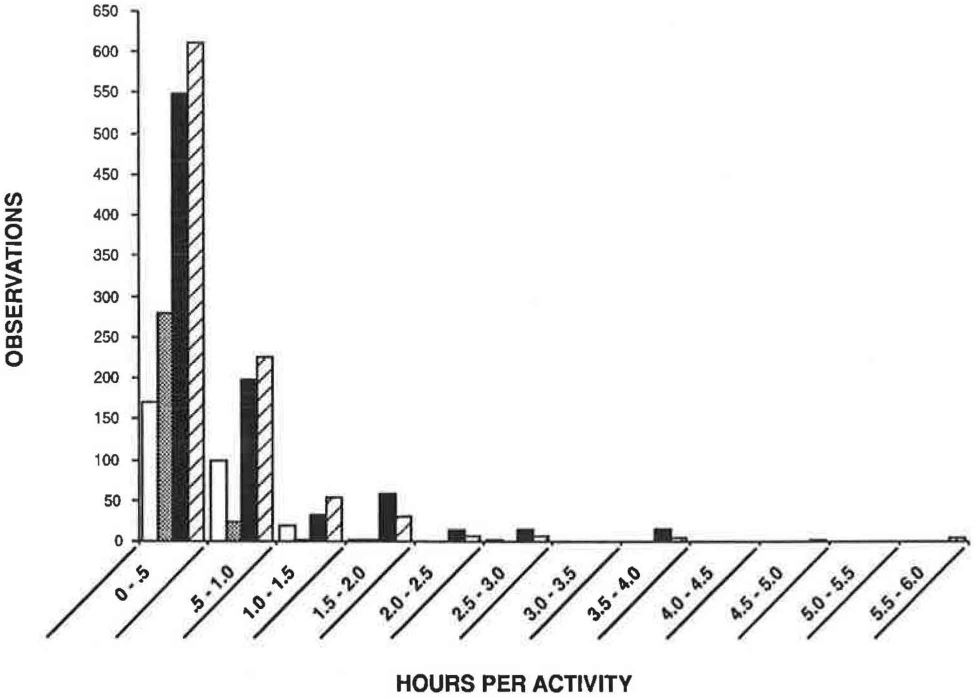
The distribution of body exterior repair times shown in Figure 6 reveals unexpected characteristics:

- The body activity code for prepare and paint occurs infrequently, suggesting that this repair is not conducted at the divisions, even though some facilities have the capability and staff.
- Heavy repairs are the second most frequent activity, accounting for approximately 43 percent of all body exterior repair hours. The average repair time of 1 hr and the large deviation (1.4 hr) indicate that complex repairs are occurring at the divisions.



☐ INSPECTION		▩ LIGHT REPAIR		■ HEAVY REPAIR		◪ REMOVE-N-REPLACE	
AVERAGE HOURS	.36	AVERAGE HOURS	.26	AVERAGE HOURS	1.86	AVERAGE HOURS	.92
STANDARD DEVIATION HOURS	.31	STANDARD DEVIATION HOURS	.25	STANDARD DEVIATION HOURS	1.39	STANDARD DEVIATION HOURS	1.23

FIGURE 5 Brake system (Object Codes 0400–0450).



☐ INSPECTION		▩ LIGHT REPAIR		■ HEAVY REPAIR		◪ REMOVE-N-REPLACE	
AVERAGE HOURS	.66	AVERAGE HOURS	.38	AVERAGE HOURS	.99	AVERAGE HOURS	.70
STANDARD DEVIATION HOURS	.54	STANDARD DEVIATION HOURS	.31	STANDARD DEVIATION HOURS	1.40	STANDARD DEVIATION HOURS	.70

FIGURE 6 Body exterior (Object Codes 2400–2437).

- Remove-and-replace repairs account for more than 35 percent of body repair hours, the second largest contributor. This activity is more in line with the functions of the divisions. The average repair time (0.7 hr) and the deviation (0.7 hr) appear reasonable, given the broad spectrum of candidate repairs (from changing light bulbs to replacing bumpers and skirt panels).
- Light repairs account for slightly more than 5 percent of all body repair hours. The low frequency of occurrence, total repair hours, and small average repair times of 0.38 hr indicate that improved productivity in this function would be difficult to achieve.
- Body inspection activity, while accounting for 10 percent of the body repair hours, can be improved on given an average inspection time of 0.66 hr or 40 min. The inspection hour figure is being influenced by the inspection for structural cracks.

For work scheduling and repair planning purposes, a preliminary standard body maintenance time of 1.5 hr should be used. This standard includes light or heavy repair times combined with inspection and remove-and-replace times.

Wheelchair-Lift Repairs

Wheelchair-lift equipment poses many difficulties for maintenance managers throughout the industry. Mechanical complications and low tolerances in clearance cause frequent problems with wheelchair-lift service and maintenance.

This investigation identified a high frequency of inspections in the 0.5- to 1-hr range, more than double the repair activity codes shown in Figure 7. Inspections occur almost four times more frequently than all other activities, reflecting the difficulties in detecting and resolving lift defects. Likewise, the large standard deviation associated with each average repair time further supports the difficulty of wheelchair-lift repairs.

A preliminary work standard of 1.5 hr should be used for planning wheelchair repairs. This standard includes sufficient time for inspection and repair.

Engine

The investigation of engine repairs conducted at the divisions was limited to light and heavy repairs, inspections, and remove-and-replace activities. The analysis included all object codes between 0800 and 0897. The broad range of object codes was expected to result in large standard deviations for each repair activity. The distribution of repairs, shown in Figure 8, confirms these expectations. However, the deviation is not as great as originally expected.

- Inspection times are relatively uniform at an average of a half-hour. This observed average should be sufficient to define specific repair requirements and to determine whether a coach should be sent to central maintenance.
- Light repairs occur the least frequently yet have the highest average repair time. The average time is influenced by

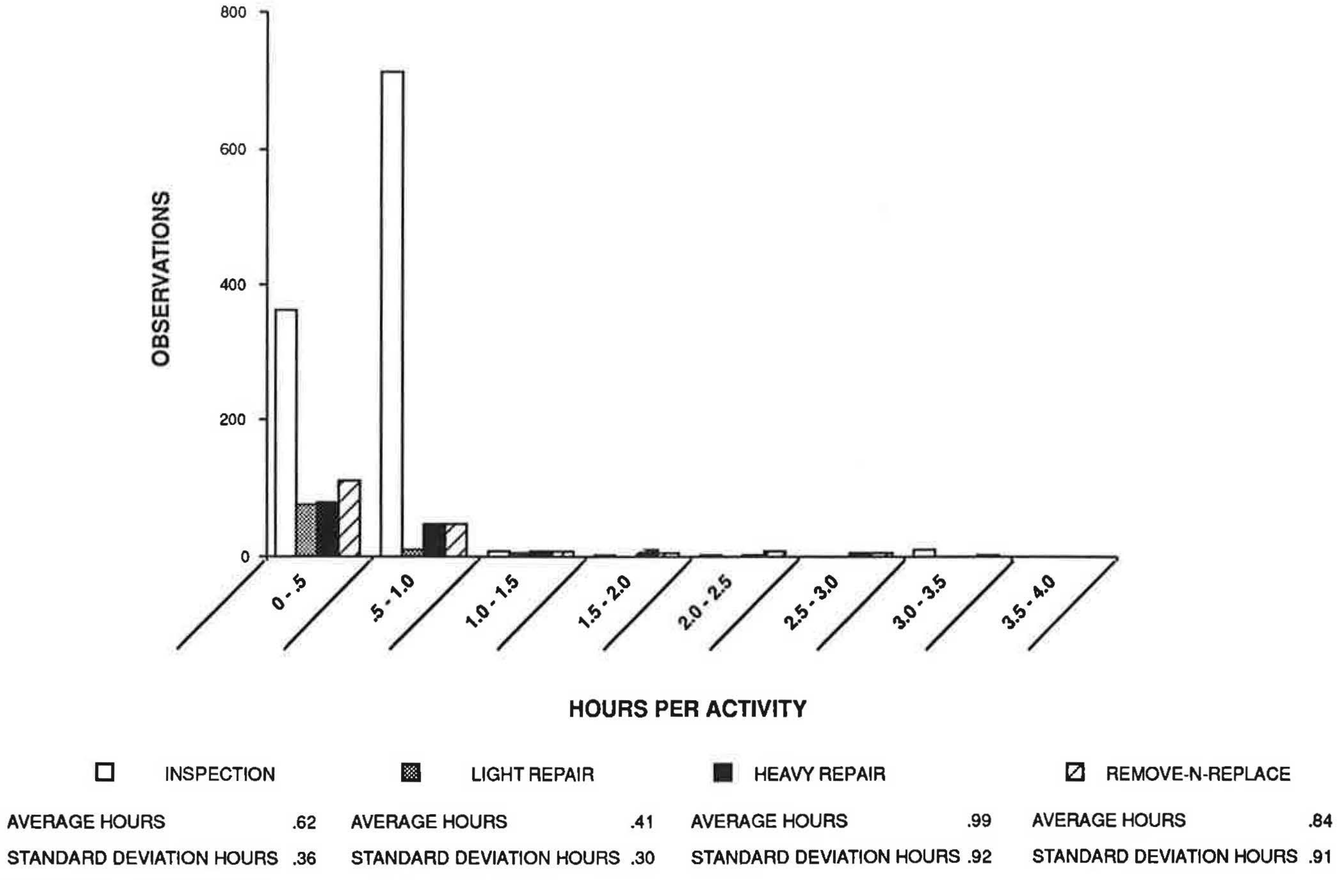
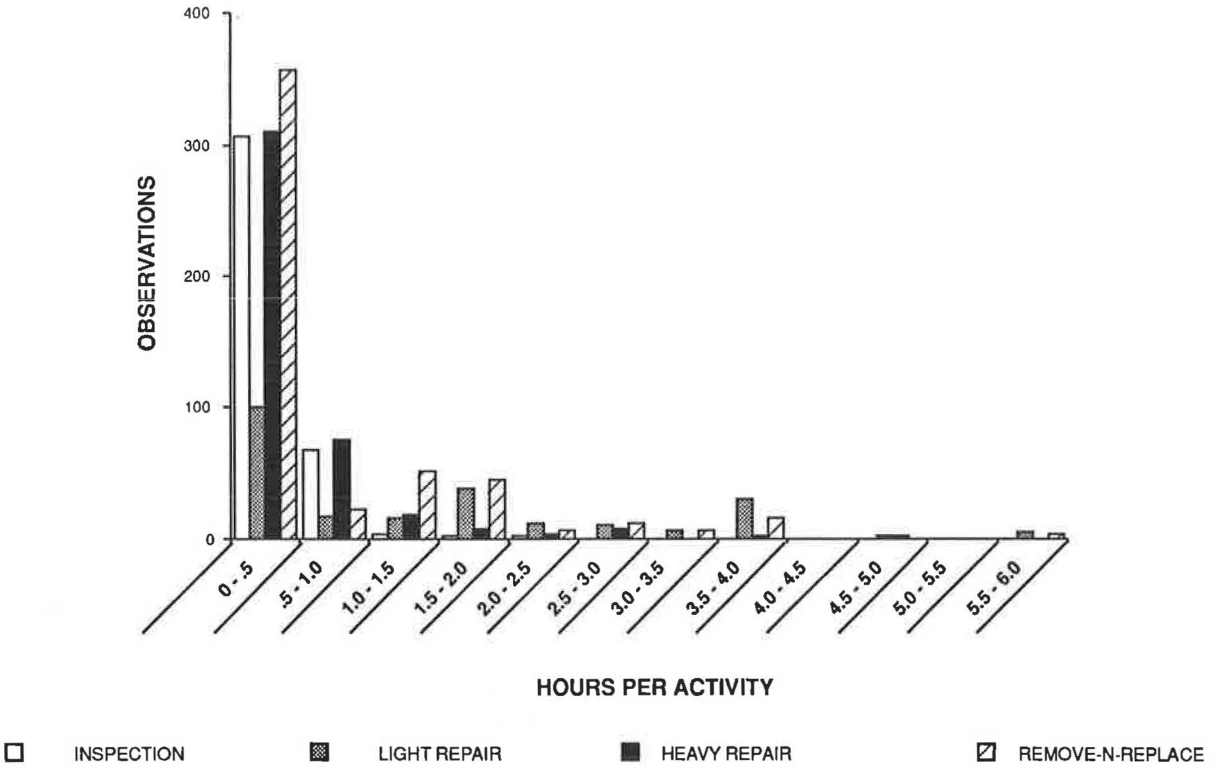


FIGURE 7 **Wheelchair lift (Object Codes 5500–5515).**



INSPECTION		LIGHT REPAIR		HEAVY REPAIR		REMOVE-N-REPLACE	
AVERAGE HOURS	.47	AVERAGE HOURS	1.78	AVERAGE HOURS	.65	AVERAGE HOURS	.98
STANDARD DEVIATION HOURS	.33	STANDARD DEVIATION HOURS	1.70	STANDARD DEVIATION HOURS	.63	STANDARD DEVIATION HOURS	1.13

FIGURE 8 Engine (Object Codes 0800–0897).

engine adjustment activities. Adjusting engine timing and other minor repairs within a 1.25-hr period is acceptable.

- The average heavy repair time of 0.65 hr reflects the policy of conducting the most significant engine repairs at central maintenance. The dominance of half-hour repairs in this category reflects running bad order (RBO) repair activities. A 40-min standard for RBO repairs should be adopted for planning purposes.
- Remove-and-replace activities are the most frequently conducted activity, as expected, because of small-component change-out schedules and the policy of sending coaches to central maintenance for major repairs. The outlying observations in the 6- to 8-hr range reflect blower and turbocharger change-outs.

The investigation provides some good preliminary engine repair work standards. Inspections should be planned to take 30 min. An engine tune-up (light repairs) combined with an inspection should be planned to take 1.0 hr. Heavy repairs (e.g., RBOs), when combined with inspection, should be planned for 1.0 hr. Likewise, most remove-and-replace activities should be planned for 1 hr. These proposed preliminary standards provide sufficient time to inspect, repair, and test engines at the divisions. The proposed division-conducted engine repair standards do not incorporate use of dynamometers.

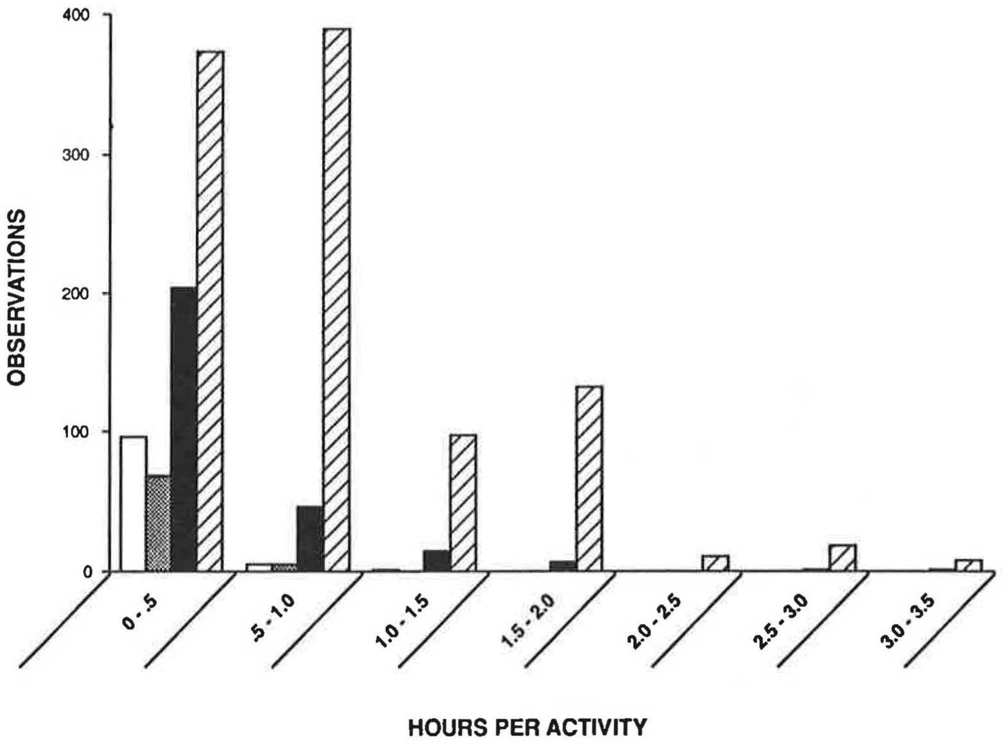
The relatively wide range of observed times for all engine maintenance activities highlights the need to tighten repair supervision. The light repairs requiring 3.5 to 4.0 hr should be rationalized. A review of division versus central maintenance repairs could improve control. Likewise, increased training in the diagnostics of engine repairs could tighten the distribution of repair times.

Air Group

Air group maintenance, like engine repairs, encompasses diverse major components including air starters, brake valves, and compressors. Many of these components have established change-out schedules that will influence the distribution of labor hour observation, as shown in Figure 9. The results of the research reveal the following:

- Inspections are typically completed within 20 min, indicating that troubleshooting an air system repair is not very difficult.
- Light repairs (e.g., adjustments) are also typically completed within 20 min.
- Heavy repairs, primarily associated with RBOs and unscheduled repairs, have only a slightly wider distribution and typically require 40 min to complete.
- Remove-and-replace activities have the widest distribution and the highest average repair time (1 hr), as expected. The complexity of removing some engine-mounted components, such as air starters and compressors, inherently broadens the distribution of repair times and increases the average.

For planning and scheduling air group repairs, the analysis indicates that a preliminary standard of 1 hr should be adopted



☐ INSPECTION		▩ LIGHT REPAIR		■ HEAVY REPAIR		☒ REMOVE-N-REPLACE	
AVERAGE HOURS	.36	AVERAGE HOURS	.32	AVERAGE HOURS	.60	AVERAGE HOURS	1.06
STANDARD DEVIATION HOURS	.23	STANDARD DEVIATION HOURS	.21	STANDARD DEVIATION HOURS	.49	STANDARD DEVIATION HOURS	3.01

FIGURE 9 Air group (Object Codes 3000–3091).

for light and heavy repairs. This standard allows for both inspection and repairs. A remove-and-replace standard of 1 hr should also be adopted. Some remove-and-replace activities were observed to require 1 to 2 hr; an additional investigation should be conducted to determine the specific components serviced in this time interval.

Suspension Repairs

The labor-hour distribution of suspension repairs by activity is influenced by the frequent occurrence of flipped leveling valves, a condition frequently caused by errant operator behavior. Flipped leveling valves account for the dominance of light and heavy repairs under a half-hour long, as shown in Figure 10.

Experience at other transit agencies indicates that suspension repair times of 1 hr are typical. Many of the suspension repairs listed in the data base involved shock absorbers. The relatively frequent shock absorber repair rate, combined with radius rod replacement, should produce an average repair time greater than the observed average of almost 1 hr. The leveling valve problem is probably the cause for the lower remove-and-replace time. The changing of a leveling valve screen explains the high frequency of remove-and-replace observations under 1 hr.

Removal of the leveling-valve-related remove-and-replace observations from the analysis increases the average remove-and-replace time to slightly under 1.25 hr. This average time is an acceptable standard for many suspension components. However, additional research is needed to establish standards for shock absorber and radius rod replacements.

Transmission

The policy of assigning all major transmission repairs except the removal and replacement of VH transmissions to central maintenance influences the distribution of repair hours, as shown in Figure 11. Almost all of the repairs occur in less than 1.5 hr. The repairs with greater duration are associated with VH transmission removal and replacement, particularly the repairs taking 5.5 to 6.0 hr and 7.5 to 8.0 hr.

Remove-and-replace activities of 0.5 hr or less are associated with transmission pans, gaskets and o-rings, and pick-up screens. The dominance of heavy repairs of this same duration is also associated with these types of transmission repairs, plus transmission fluid leaks.

Inspections primarily involve the determination of where repairs should be performed (at division or central maintenance). In fact, the difference in time distributions of the four repair activities is small, indicating that mechanics are probably using different activity codes for similar repairs. Increased supervision of repairs and proper recording of activity codes on the work order should increase the relative differences in repair time distributions.

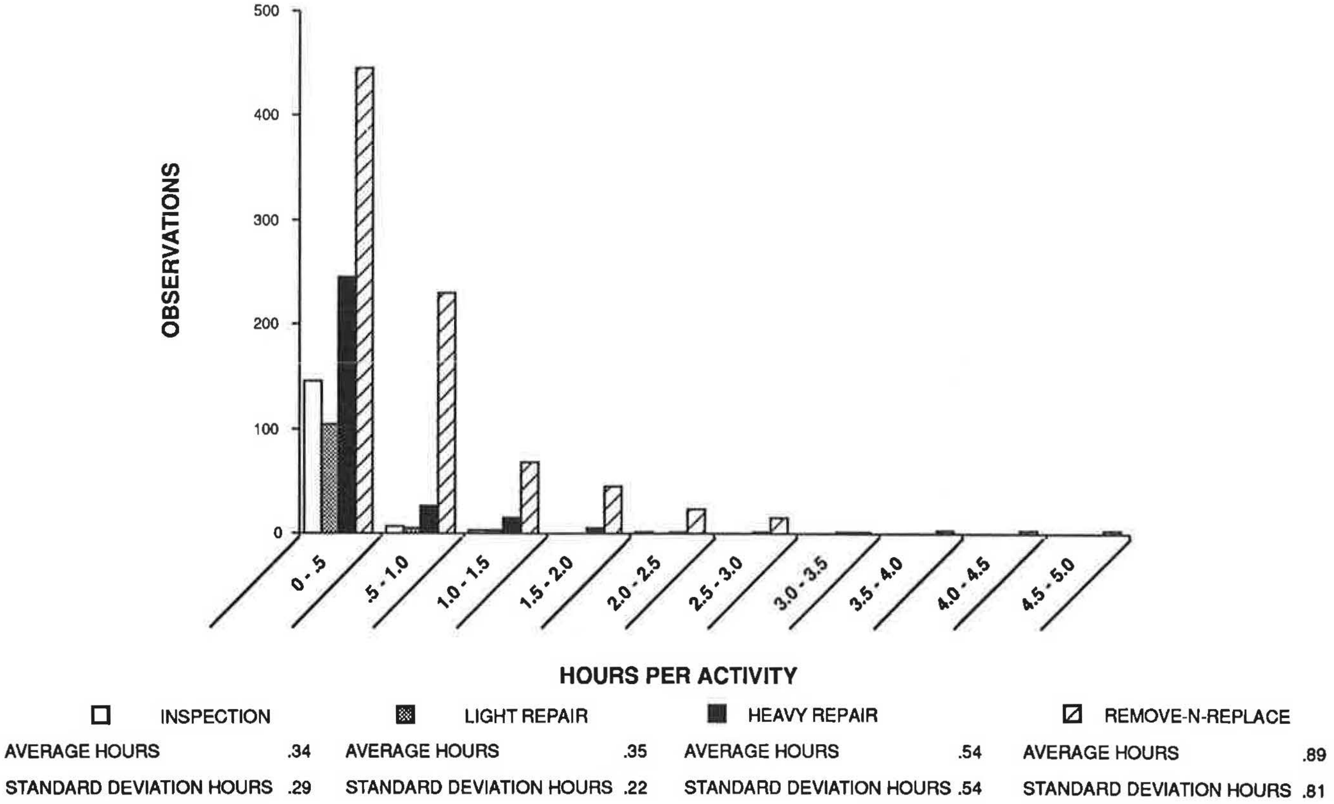


FIGURE 10 Suspension (Object Codes 1400–1492).

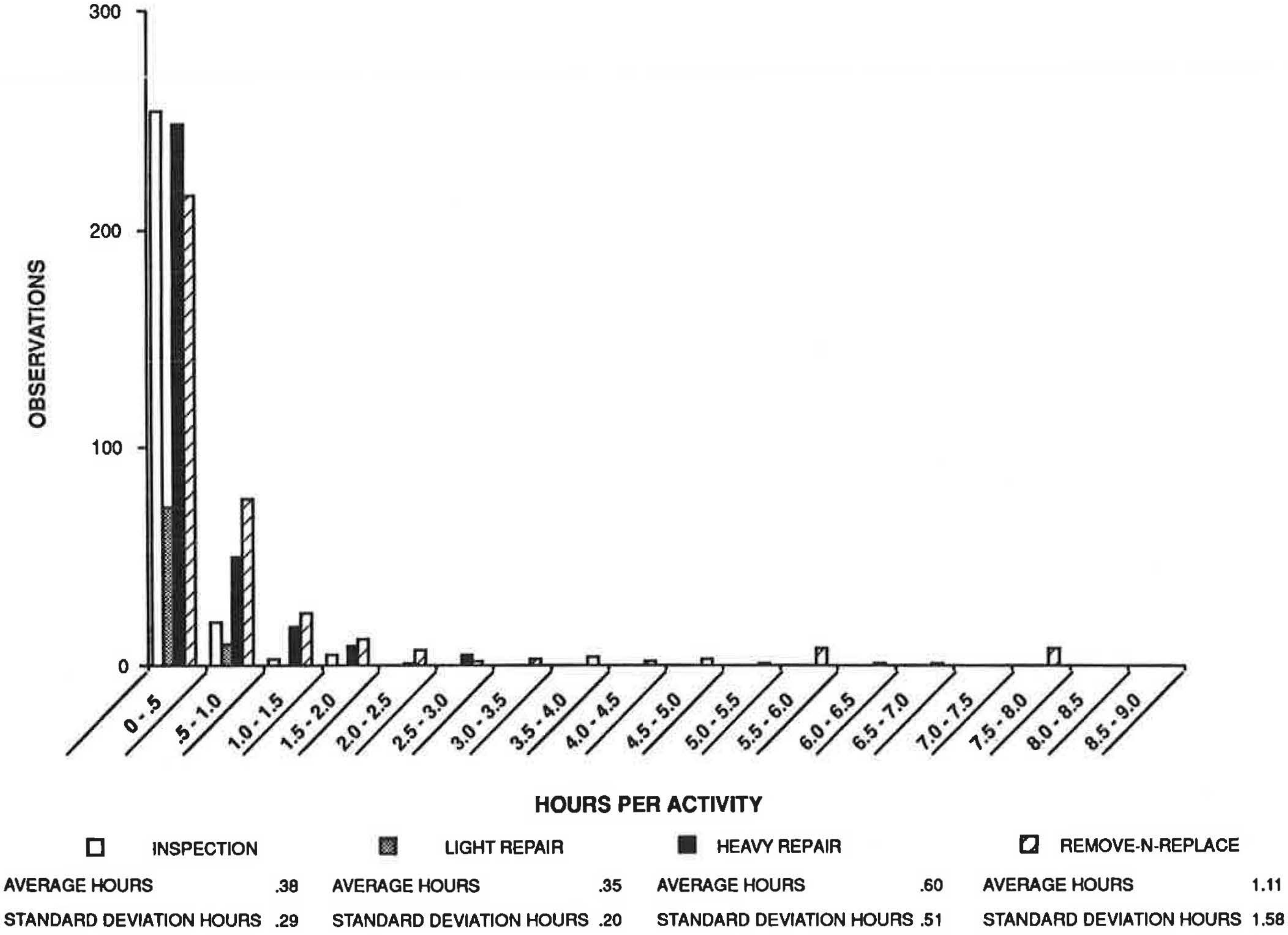


FIGURE 11 Transmission (Object Codes 1700–1792).

On the basis of these observed repairs, a preliminary work standard for division-performed transmission repairs should be 0.5 hr for inspections. The time standard for light repairs should be 0.75 hr and for heavy repairs, 1.0 hr. These standards incorporate both the inspections and the diagnostic phase of repair. For VH transmissions, a remove-and-replace standard of 6.0 hr should be used. A 6-hr standard indicates that the work can be completed in one shift by trained mechanics while still allowing for unproductive times such as report, clean-up, breaks, and lunch periods. Increased attention to the correct recording of activity codes on repair orders should decrease the number of remove-and-replace observations by a little less than 5 hr.

Cooling System

The final major component group is the cooling system. This group accounted for 3.5 percent of the divisions' repair labor hours. The individual components within the group cover both water- and oil-cooling equipment.

The results of the research, shown in Figure 12, indicate that most repairs are performed in less than 1 hr. The dominant repair is component remove-and-replace activity. The frequency of remove-and-replace activities lasting less than 0.5 hr reflects the changing of filters. Removing the filter-change observations from the data base increases the average remove-and-replace time to 1.4 hr. This duration is representative for the change-out of coolers, pumps, radiators, and heater cores. The replacement of pipes and hoses is expected to take less time. Therefore, a preliminary remove-and-replace standard for cooling system components, excluding filters, should be 1.5 hr. Obviously, some repairs will take longer, but the 1.5-hr standard provides managers with a planning benchmark.

Heavy repair activity is the second most frequent repair. Few heavy repair times were greater than 1.5 hr. For planning purposes, a preliminary standard of 1.0 hr, which includes inspection and repair times, should be used.

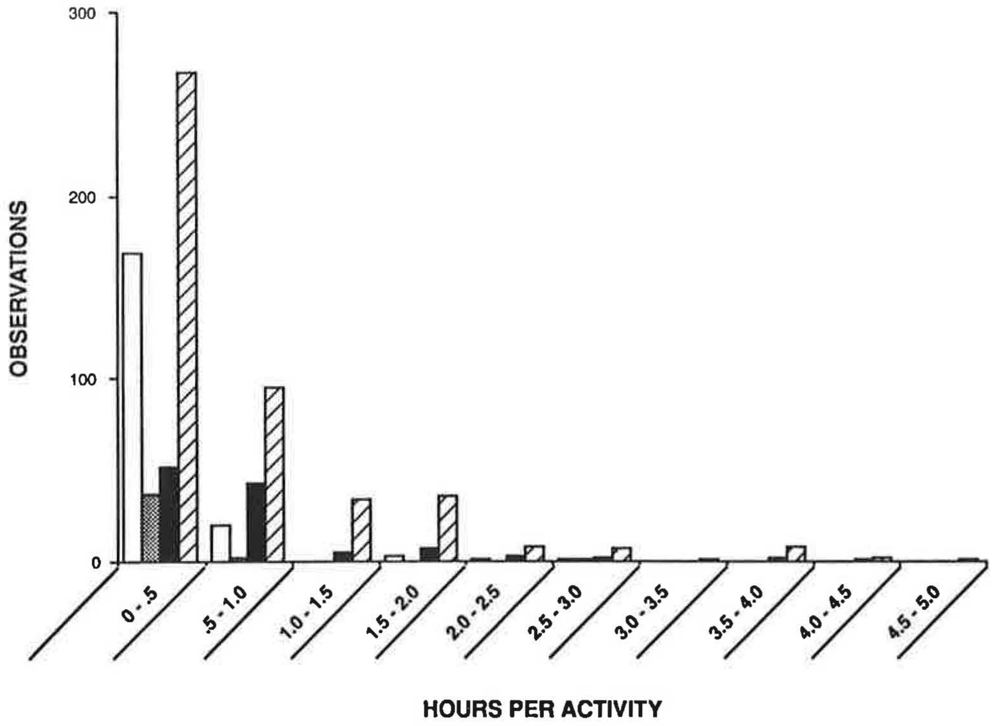
Too few light repair observations were contained in the data base to draw any conclusions.

IMPLICATIONS FOR MAINTENANCE MANAGERS

To plan and control maintenance cost, managers must understand how resources are applied and must apply tools to increase the use of applied resources. This methodology illustrated the use of MMISs to identify preliminary work standards for planning and controlling workforce labor.

The methodology also identified opportunities for improved performance through the evaluation of specific repair activities. The use of engineering resources to address repair time groups that vary significantly from observed repair time averages provides maintenance managers with additional opportunities to control resources.

The research identified 10 component groups that account for more than 85 percent of maintenance labor. To improve



□ INSPECTION		▩ LIGHT REPAIR		■ HEAVY REPAIR		☒ REMOVE-N-REPLACE	
AVERAGE HOURS	.43	AVERAGE HOURS	.38	AVERAGE HOURS	.68	AVERAGE HOURS	.95
STANDARD DEVIATION HOURS	.39	STANDARD DEVIATION HOURS	.45	STANDARD DEVIATION HOURS	.73	STANDARD DEVIATION HOURS	1.02

FIGURE 12 **Cooling system (Object Codes 0600–0692).**

maintenance performance by providing managers a guideline for planning and controlling maintenance activities, 23 standards were identified. By applying these preliminary work standards, workforce use can be improved and the need for additional mechanics avoided. Increasing productivity levels by 10 percent, a feasible objective through use of standards, would prevent the need to hire additional mechanics (*4*). The application of a maintenance manpower planning model indicated that a 10-mechanic shortage was present at the host agency (*6*). This labor shortage could be overcome by the use of preliminary standards.

The preliminary work standards presented here can be applied to transit operations across the country. More valuable to maintenance managers is the illustration of the methodology used to develop the initial standards. This methodology can be applied by managers responsible for all aspects of maintenance, regardless of industry affiliation.

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PART 2

Finance

Financial Capacity Analysis of the San Francisco Bay Area Rail Extension Program

Albert Huerby, Nancy E. Whelan, and Dennis L. Markham

The purpose of the Bay Area Transit Finance Plan was to determine the financial capacity of the region to fund a multioperator rail extension program into the next century. The 21 proposed rail extension projects were grouped into 5 alternative regional packages. The financial impacts of these alternatives were assessed against ongoing funding required to operate, maintain, and recapitalize the existing eight-operator regional transit system in the Bay Area. The cumulative financial position at the end of 10- and 20-year periods was calculated for each transit operator and the entire region from a microcomputer-based cash flow model. The cash flow model integrated annual operating costs and revenues, vehicle and facility replacement, rail extension capital costs, and projected funding from dedicated existing sources as well as proposed new revenue sources. It was determined that the region had the financial capacity to operate, maintain, and recapitalize its existing transit system. However, it was found that the region would experience a cumulative deficit of $1.1 billion at the end of 10 years if the regionally preferred rail extension program was implemented, unless additional revenues could be made available. A series of funding recommendations were proposed that were consistent with proposals being advanced at state and county levels and, if implemented, would eliminate the 10-year cumulative deficit. These proposals have subsequently either been enacted or are in the process of being enacted into law.

The Bay Area Transit Finance Plan was initiated in 1987 when the Federal Mass Transportation Act (Section 331) directed the region to develop financing alternatives for the first-phase rail extensions identified in the Regional Transportation Plan. The Metropolitan Transportation Commission (MTC), which is the regional transportation planning agency for the nine-county San Francisco Bay Area, was assigned this responsibility by UMTA. The firms of Deloitte & Touche, then Deloitte Haskins & Sells, were retained by MTC to conduct the study.

The study commenced in February 1988 and included an analysis of the region's eight largest transit operators:

- Alameda-Contra Costa Transit District (AC Transit), which operates an 850-bus system in Alameda and Contra Costa Counties;
- Bay Area Rapid Transit District (BART), which operates a 71-mi heavy-rail system linking San Francisco to Oakland and suburban Alameda and Contra Costa Counties;
- CalTrain, which operates commuter rail service between San Francisco and San Jose;
- Central Contra Costa Transit Authority (CCCTA), which provides local bus service in Contra Costa County;
- Golden Gate Bridge, Highway, and Transportation District (GGBHTD), which operates local and commuter bus and ferry service between San Francisco and Marin County;
- San Francisco Municipal Railway (MUNI), which operates bus, trolley, cable car, and light rail service within San Francisco;
- San Mateo County Transit District (SamTrans), which operates bus service within San Mateo County and to San Francisco; and
- Santa Clara County Transit District (SCCTD), which operates local bus and light rail service in San Jose and Santa Clara County.

A key objective of the study was to determine if these transit operators would have sufficient financial capacity through the year 2000 to

- Continue current and anticipated service levels;
- Rehabilitate and replace required vehicle fleets and facilities; and
- Finance major extensions of the BART heavy-rail system, extend commuter rail service into downtown San Francisco, and extend light-rail service into northern Santa Clara County.

The study was also designed to examine significant funding priority issues that had been under debate in the region for several years. These issues included such concerns as

- Could a West Bay extension of BART to the San Francisco International Airport be constructed concurrent with extending BART to one destination in Contra Costa County and two in Alameda County?
- What would the financial implications be for Bay Area operators when the state of California ceased its 50 percent operating subsidy of the peninsula commuter service (CalTrain) between San Jose and San Francisco?

These and other politically and financially sensitive issues required detailed analyses to determine the tradeoffs required to maximize the use of locally generated funds for supporting and extending transit services throughout the region.

The background to the study, the financial methodology used in the analysis, the assumptions on which the study was

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based, and the principal findings and conclusions are discussed in the following sections.

BACKGROUND

The Bay Area relies heavily on local funding for transit. Examples of local funding support include countywide half-cent sales taxes for transit districts in five of the nine Bay Area counties, regional toll bridge revenues dedicated to transit, and the dedication of more than $100 million annually to MUNI from the San Francisco general fund.

In recent years, existing transit funding has been sufficient to operate and maintain transit services provided by the eight major Bay Area transit operators and to allow for gradual expansion of service while keeping fare increases to the level of inflation. However, MTC believed that a major rail expansion program would require significant new revenue sources at the local level along with increased federal and state funding participation. This financing challenge was made more difficult by recent cutbacks in federal and state funding to the Bay Area, which in 1989 was $67 million below 1984 levels.

Twenty-one rail extension projects had been proposed by five Bay Area transit districts and the California Department of Transportation, which operates CalTrain. The total cost for these proposed extensions exceeded $4.5 billion (in 1987 dollars). Each project had its proponents, but no decisions about project priorities or funding sources and amounts had been reached before this study began.

During the study, a Regional Rail Agreement was reached between SamTrans and BART for the funding and construction of a BART extension to the San Francisco airport. The 25 percent local share of this extension will be financed mostly by the half-cent sales tax that has been collected for transit service in San Mateo County since 1981. This sales tax will also provide the revenue contributions of Alameda and Contra Costa Counties. A map of these proposed projects is shown in Figure 1. Additional local funding commitments for these projects will come from additional half-cent sales tax initiatives in Alameda, Contra Costa, and San Mateo Counties and from a 25-cent increase in bridge tolls. Voters were asked to approve countywide half-cent sales taxes and bridge toll increases with the revenues dedicated to specific rail, bridge, and highway projects. The sales tax measures are designed to sunset after 10, 15, and 20 years.

FINANCIAL PLANNING ISSUES

In the Bay Area, transit planning is primarily the responsibility of the transit operators that use the UMTA-sponsored Short Range Transportation Planning (SRTP) process. The 5-year plans are updated and submitted to MTC annually.

Although the planning process includes a short-range outlook for capital replacement requirements for each operator, no assessment had been made of the region's aggregate transit capital replacement needs over an extended period of time, nor had the potential competition for funds between recapitalization needs and rail extension projects been examined. The financial capacity question was further complicated by the following factors:

- Rail extension costs and the proposed funding for the rail program were uncertain. Only preliminary project cost estimates were available. Questions remained about whether proposed revenues would be sufficient to deliver all the projects voters would be asked to endorse.
- The program relied on multiple funding sources, which were the subject of voter approval in the June and November ballots. Hence, there was uncertainty about several voter outcomes.
- UMTA had authorized two alternatives analyses studies in the Bay Area. However, preliminary results indicated that some projects would not meet UMTA cost-effectiveness criteria, thereby limiting potential federal Section 3 New Start funding participations.
- UMTA had also raised questions regarding the long-term financial viability of the region's transit operators given the magnitude of the proposed rail expansion program, limited federal funds, and the need to continue to operate and recapitalize existing services. These questions required resolution throughout the study.

To provide answers to these regional financial planning issues, UMTA agreed to fund the Bay Area Transit Finance Plan effort. This study was not designed to evaluate the particular merits of individual extension projects. Rather, its key objectives were to

- Analyze the financial capacity of the Bay Area's transit operators to continue service while adequately maintaining their physical plants and providing necessary vehicle replacements,
- Provide an objective analysis of the region's capacity and capability to finance the rail projects contained in the Regional Rail Agreement,
- Develop analytical tools and methodologies to analyze the financial implications of alternative rail development scenarios, and
- Assist in developing project priorities on the basis of common assumptions and financial realities.

In meeting these objectives, the finance plan focused on the eight largest public transit operators in the Bay Area, whose operating statistics are presented in Table 1.

METHODOLOGY

The primary analytical tool used in developing the Bay Area Transit Finance Plan was a detailed cash flow model. In the model, all revenues, expenditures, and net cash positions were computed at the end of each fiscal year for each operator and for the region as a whole over the 30-year (1988 to 2017) analysis period. A sample spreadsheet is presented in Table 2.

Three basic levels of analyses were performed:

- Baseline,
- Enhanced baseline, and
- Expansion alternatives.

The baseline consisted of the operators' existing (FY 1988) levels of service and the capital replacements required to

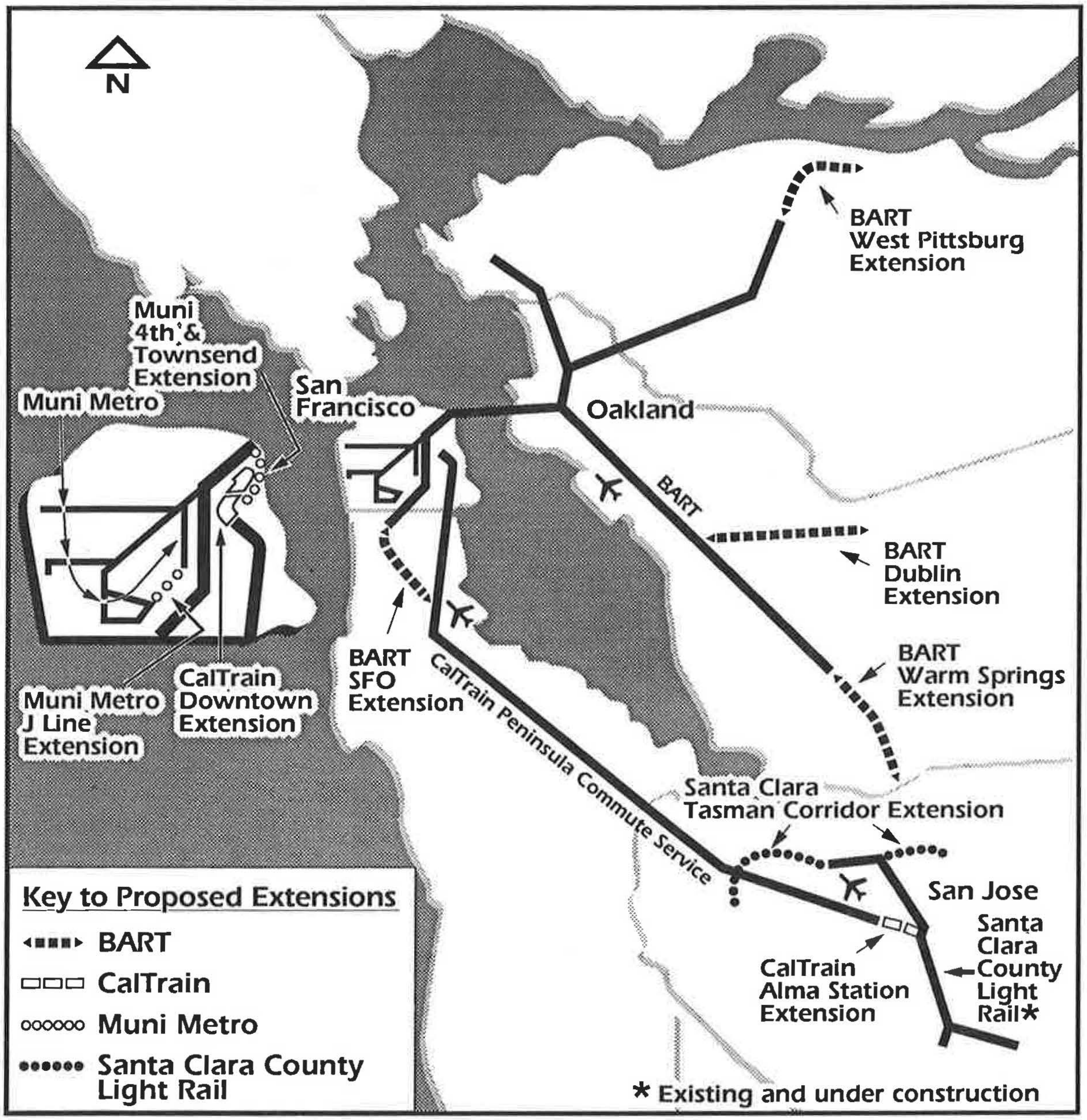

FIGURE 1 MTC rail extension program.

maintain existing service. This analysis served as a preliminary test of financial capacity for the region.

The enhanced baseline reflected existing service plus certain service enhancements and capital projects programmed or included in the operators' current short-range transit plans.

The expansion alternatives comprised the enhanced baseline services plus proposed rail expansion projects. Twenty-one proposed rail expansion projects were included in the analysis. These projects were grouped into five "packages" according to the potential future availability of local sources of funds. The Regional Rail Agreement projects, which were examined in Package A, formed the basis for the composition of subsequent Packages C, D, F, and G. (Packages B and E were eliminated during the study.) The packages are presented in Table 3.

To ensure accuracy in the data, methods, and assumptions used to develop the finance plan, MTC established a Bay Area Transit Finance Plan Task Force. The task force, composed of representatives from each of the eight transit operators, met approximately once a month to review progress on the plan and to comment on the validity of the findings and conclusions. Additional meetings were held with individual operators as needed.

ASSUMPTIONS

More than 75 detailed assumptions and decision rules governing the flow of funds were formulated. These were reviewed by the task force during the study and are documented in five

TABLE 1 EIGHT MAJOR TRANSIT OPERATORS IN THE SAN FRANCISCO BAY AREA (1987–1988 STATISTICS)

	OPERATING DATA		SOURCES OF OPERATING FUNDS ($ millions)							TOTAL OPERATING EXPENSES ($ millions)
			LOCAL/REGIONAL				STATE	FEDERAL		
TRANSIT OPERATOR	ACTIVE FLEET	AVERAGE WEEKDAY BOARDINGS	USER (FARES)	LOCAL TAXES	TDA	AB 1107	STA	UMTA	OTHER	
A.C. TRANSIT	815	211,000	$30.1	$27.5	$25.3	$15.2	$0.900	$7.0	$7.6	$113.8
BART	465	202,500	78.4	76.0	0.3	0.0	0.500	0.0	5.2	160.6
CALTRAIN	73	16,000	9.5	0.0	3.7	0.0	0.000	1.2	11.3	25.9
CCCTA	101	14,300	1.7	0.0	7.9	0.0	0.000	1.4	0.4	10.6
GGBHTD	243	30,400	14.4	0.5	6.8	0.0	0.031	1.7	14.1	37.7
S.F. MUNI	1,013	801,200	71.1	115.6	17.0	15.2	0.500	8.7	7.8	236.2
SAMTRANS	299	61,500	7.7	13.0	11.5	0.0	0.008	1.6	4.0	34.5
SCCTD	529	118,500	11.3	56.5	34.3	0.0	0.000	6.9	(0.5)	108.6
REGIONAL TOTAL	3,538	1,455,400	$224.2	$289.1	$106.8	$30.4	$1,939	$28.5	$49.9	$727.9

TABLE 2 CASH FLOW SPREADSHEET

REGIONAL SUMMARY (inflated $millions)	PACKAGE: ENHANCED											
	YR 1-10 SUBTOTAL	YR 1-20 SUBTOTAL	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
OPERATIONS		Opening Balance:	107.1									
REVENUE		Reserve Balance:	0.0									
Interest on Short Term Cash	120.0	999.0	6.4	7.2	8.7	9.4	9.9	10.8	11.9	14.4	18.3	22.9
Fare	2,701,8	7,278.5	216.5	220.2	233.1	244.6	259.0	274.8	290.4	304.4	320.7	338.1
Other Operating	134.4	362.0	10.7	11.0	11.6	12.2	12.9	13.7	14.4	15.1	15.9	16.8
TDA	1,529.5	4,724.1	110.1	117.6	125.1	133.8	144.3	155.1	166.7	178.6	191.8	206.6
AB 1107	1,718.1	5,234.2	123.4	132.4	141.4	151.3	162.5	174.1	186.9	200.0	214.9	231,2
Sales Tax	1,583.9	4,989.6	114.8	122.0	129.2	137.9	149.1	160.5	172.7	185.1	198.7	214.1
Section 9	267.3	534.6	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
STA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Property Tax/General Fund	1,613.0	4,488.2	144.2	135.1	137.7	144.8	152.2	159.6	168.9	178.6	189.8	201.9
Transfer Payments In	296.2	811.7	22.9	23.9	25.0	26.1	17.4	30.8	32.4	34.0	35.9	37.9
Other Local	166.9	391.4	14.1	14.3	15.8	16.1	16.5	17.0	17.4	17.9	18.6	19.2
Debt Service - Operating	(159.3)	(325.3)	(15.0)	(15.8)	(15.8)	(15.9)	(16.0)	(16.0)	(16.1)	(16.2)	(16.2)	(16.3)
TOTAL OPERATING REVENUES	9,972.0	29,437.8	774.8	794.7	838.5	887.1	944.5	1,007.1	1,072.3	1,138.8	1,215	1,299
EXPENDITURES												
Existing Baseline	8,884.4	23,698.6	733.0	740.7	780.0	812.9	853.1	896.0	943.0	988.2	1,041	1,097
Enhancements	287.0	1,027.8	0.0	3.7	7.4	14.3	27.1	38.9	45.0	47.4	50.0	53.1
New Starts and Extensions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Transfer Payments Out	272.2	788.2	15.2	15.8	16.5	26.1	27.4	30.9	32.4	34.0	35.9	37.9
TOTAL ANNUAL O&M EXPENDITURES	9,443.7	25,514.8	748.2	760.2	803.9	853.3	907.7	965.8	1,020.4	1,069.7	1,127	1,188
OPERATING SURPLUS (DEFICIT)	528.3	3,923.0	26.6	34.5	34.6	33.8	36.8	41.3	51.9	69.1	88.5	111.2
CUMULATIVE OPERATING SURPLUS (DEFICIT)	389.5	3,241.6	131.8	156.5	139.9	151.3	157.5	164.8	205.0	252.3	312.0	389.5
OPERATING RATIO	30.92%	30.90%	30.99%	31.07%	31.08%	31.04%	30.89%	30.86%	30.85%	30.86%	30.86%	30.86%
TRANSFER TO CAPITAL	234.9	769.3	0.0	9.5	50.7	22.4	30.1	33.2	10.3	20.6	26.5	31.6
TRANSFER TO CAPITAL FOR REQUIRED MATCH	11.1	19.2	1.9	0.4	0.4	0.0	0.5	0.8	1.4	1.3	2.3	2.1

TABLE 2 *(continued on next page)*

TABLE 2 (*continued*)

REGIONAL SUMMARY (inflated $millions)	PACKAGE: ENHANCED											
	YR 1-10 SUBTOTAL	YR 1-20 SUBTOTAL	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
CAPITAL												
REVENUE - EXISTING	Opening Balance:	312.5										
Transfer from Operations	234.9	769.3	0.0	9.5	50.7	22.4	30.1	33.2	10.3	20.6	26.5	31.6
Article XIX	93.0	351.6	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
Section 9	536.1	1,072.2	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6
Section 3 - Rail Mod.	400.0	800.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Section 3 - New Starts	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bridge Tolls	145.2	294.3	27.4	11.8	12.2	12.5	12.9	13.2	13.4	13.7	13.9	14.2
TP&D	100.0	200.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Transfer from Ops (Matching)	11.1	19.2	1.9	0.4	0.4	0.0	0.5	0.8	1.4	1.3	2.3	2.1
SUBTOTAL - EXISTING CAPITAL REVENUE	1,520.2	3,506.6	142.2	134.6	176.2	147.8	156.4	160.1	138.0	148.5	155.6	160.8
REVENUE - NEW												
Transfer Payments In	110.6	112.9	0.0	5.9	55.4	22.8	18.5	7.6	0.0	0.4	0.0	0.0
Bond Proceeds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Interest Income	126.5	208.0	15.5	18.4	24.1	18.5	12.9	10.0	7.2	6.5	6.7	6.7
Additional Sales Tax	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Local	26.0	80.2	0.0	4.7	9.8	0.7	0.2	2.5	0.0	0.8	0.7	6.6
Interstate Transfer Funds	23.3	23.3	0.0	2.5	0.3	20.5	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL CAPITAL REVENUE	1,806.6	3,931.0	157.7	166.1	265.8	210.4	188.0	180.3	145.2	156.1	162.9	174.1
EXPENDITURES												
Rail Extension & Other Projects	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Transfers Out	110.6	110.6	0.0	5.9	5.4	22.8	18.5	7.6	0.0	0.4	0.0	0.0
Replacement Costs	1,364.4	3,653.3	31.5	35.4	203.1	109.7	150.9	100.3	104.0	239.3	183.6	206.7
Int. Cost of Deferred Capital Expenditures	28.0	96.8	0.0	0.0	0.0	0.1	0.5	2.8	6.1	5.2	6.4	6.9
Enhancements	920.7	920.7	27.7	142.9	175.3	144.1	174.8	254.6	1.5	0.0	0,0	0.0
SUBTOTAL - OTHER CAPITAL EXPENDITURES	2,423.7	4,781.4	59.2	184.2	433.7	276.6	344.7	365.3	111.6	244.9	190.0	213.6
TOTAL CAPITAL EXPENDITURES	2,423.7	4,781.4	59.2	184.2	433.7	276.6	344.7	365.3	111.6	244.9	190.0	213.6
CAPITAL SURPLUS (DEFICIT)	(617.0)	(850.5)	98.5	(18.1)	(167.9)	(66.2)	(156.7)	(185.1)	33.6	(88.8)	(27.0)	(39.5)
CUMULATIVE CAPITAL SURPLUS (DEFICIT)	(304.5)	(538.0)	411.0	392.9	225.0	158.8	2.1	(182.9)	(149.3)	(238.0)	(265.1)	(304.5)
LESS: TOTAL TRANSFERS TO CAPITAL	246.0	788.5	1.9	9.9	51.1	22.4	30.6	34.0	11.7	21.9	28.8	33.7
CUMULATIVE COMBINED SURPLUS (DEFICIT)	84.9	2,703.6	542.8	549.4	365.0	310.1	159.6	(18.2)	55.7	14.2	46.9	84.9

technical reports. The key revenue and expenditure assumptions are summarized in the following subsections.

Revenue Assumptions

Fares

For each operator, a constant farebox recovery ratio (fare revenue divided by operating cost) was assumed on the basis of 5-year historical trends and 5-year projections. This ratio was used to calculate fare revenue.

TDA and Local Sales Tax

Transportation Development Act (TDA) and local half-cent sales tax revenues were estimated for each county using a Deloitte & Touche sales tax projection model. Key variables included in the model were population and disposable income. The projections also reflected historical trends.

Section 9 (Operating)

It was assumed that the San Francisco/Oakland urbanized area would continue to receive $20 million annually and the San Jose area would receive $6.8 million annually.

State Article XIX Funds

It was assumed that $30 million would be available to the region annually. From this would come $248 million dedicated to BART's four extension projects. The remaining funds were allocated to operators according to their share of the region's capital requirements each year.

TP&D

State transportation planning and development (TP&D) funds were assumed to be $10 million annually to the region. TP&D funds were allocated to transit operators on the basis of their share of the region's annual capital requirements.

Federal Capital

The following amounts were assumed to be available annually:

- Section 9, San Francisco/Oakland urbanized area—$46.3 million;
- Section 9, San Jose urbanized area—$7.4 million; and
- Section 3, rail modernization—$40.0 million.

These funds were allocated to operators according to their annual share of the region's capital requirements.

TABLE 3 PACKAGES AND COMPONENT RAIL PROJECTS (1987 DOLLARS, IN MILLIONS)

PACKAGES AND PROJECTS	MILES	COST PER PACKAGE	COST WITH PACKAGE A
PACKAGE A			
BART			
Daly City to Colma	0.3	$82.4	
Colma to San Francisco Airport	10.9	388.1	
Fremont to Warm Springs	5.5	337.7	
Bayfair to Dublin	11.6	181.4	
Concord to North Concord	2.6	150.8	
North Concord to West Pittsburg	5.0	126.5	
CALTRAIN			
Downtown Extension	1.5	$443.5	
SCCTD			
Sunnyvale/Mt. View to Lockheed	8.2	$160.3	
Lockheed to Ironsides	2.9	51.2	
1st Street LRT Station to Milpitas	2.4	33.7	
Milpitas to Cropley	1.8	56.9	
Gilroy Caltrain Extension	29.9	29.2	
TOTAL PACKAGE A	82.6	$2,041.7	$2,041.7
PACKAGE C - Package A plus:			
BART			
Warm Springs to Milpitas	6.3	297.5	
Milpitas to San Jose	7.3	765.2	
SCCTD			
Vasona Corridor LRT to Vasona Junction	5.9	116.0	
TOTAL PACKAGE C	19.5	$1,178.7	$3,220.4
PACKAGE D - Package A plus:			
BART			
Richmond to Interstate 80	8.0	$435.0	
Dublin to East Pleasanton	2.0	36.6	
East Pleasanton to East Livermore	9.2	161.0	
West Pittsburg to East Antioch	8.5	285.0	
TOTAL PACKAGE D	27.7	$917.6	$2,959.3
PACKAGE F - Package A plus:			
MUNI			
Bayshore Project	TBD	$8.7	
TOTAL PACKAGE F		$8.7	$2.050.4
PACKAGE G - Package A plus:			
MARIN & SONOMA COUNTIES			
Marin-Sonoma Light Rail Transit	TBD	$392.5	
TOTAL PACKAGE G		$392.5	$2,434.2

Section 3 New Start funds were assumed to be available to the region in the amount of 27 percent of the capital costs for Package A. This amount represented 75 percent federal funding participation on only the BART airport extension and 27 percent federal funding for the Santa Clara County light rail extensions examined in Package A.

Bridge Tolls

On the basis of MTC policy, 30 percent of the annual state bridge toll revenues from existing collections were allocated to MUNI and 70 percent to AC Transit, BART, and CCCTA. The bridge toll increase implemented on January 1, 1989, was assumed to yield $10 million per year, with 70 percent to be distributed to BART and the remainder to the West Bay according to the MTC Regional Rail Agreement.

Capital Cost Assumptions

Costs for rail extensions and existing capital replacements were estimated for the 30-year period. Capital assets for each operator (excluding land) were identified for four asset categories: revenue vehicles, nonrevenue vehicles, fixed facilities, and equipment. Using assumptions for unit costs and useful life, replacement costs and schedules were developed for all assets. An annual total cost for capital replacements was estimated for each operator over the 30-year projection period.

Capital costs for the rail extensions were based on planning studies, alternatives analyses, and conceptual-level work estimates and are subject to refinement.

Operating and Maintenance Cost Assumptions

For each operator, operating and maintenance cost estimates were prepared for the baseline, enhanced baseline, and extension scenarios. Operating and maintenance costs were either provided directly by GGBHTD and MUNI or projected from cost models developed in recent regional studies. Disaggregate operating and maintenance cost models were developed for BART, SCCTD, AC Transit, CCCTA, and SamTrans. An aggregate cost model was developed for CalTrain on the basis of budget information contained in its short-range transit plan.

Package A Funding Assumptions

As part of the Regional Rail Agreement, MTC prepared a matrix to indicate individual fund sources and their dedication to projects, according to previous cost and revenue analyses. This matrix, presented in Table 4, served as the basis for assumptions and formulas used in the cash flow model.

FINDINGS AND CONCLUSIONS

Baseline

The baseline cash flow analyses indicated the following:

- The region has the financial capacity to fund existing transit services and capital replacements over the next 10 years.
- During that time period, MUNI will incur a cumulative deficit of approximately $107 million in funding its baseline service and making transfer payments to CalTrain for capital and operating costs. This deficit is largely attributed to a projected reduction of San Francisco's general fund support to MUNI and to the cumulative impact of recent cuts in UMTA Section 9 operating subsidies. MUNI's cumulative deficit would be reduced to $98 million if the state continued to subsidize CalTrain's operations and maintenance costs at current levels.
- CalTrain currently receives transfer payments from MUNI, SCCTD, and SamTrans to offset part of its capital and operating deficit. Without these payments, CalTrain would require approximately $292 million from the state over the next 10 years.

Enhanced Baseline

A summary of each operator's cumulative 10-year position for the enhanced baseline is presented in Table 5. The table presents the cumulative positions of the operators with and without transfer payments to CalTrain for capital enhancements. Key findings and conclusions are as follows:

- Over the 10-year period, all operators except MUNI are capable of funding their enhanced baseline operating and capital costs, including payments made to CalTrain to offset its deficits. MUNI would incur a cumulative deficit of $565.1 million.
- CalTrain would require additional capital subsidies of $110.5 million from external sources, primarily to fund right-of-way purchases. If the state terminated its subsidy of CalTrain operations, the region's reliance on local funding sources would increase by an additional $103 million.
- A maximum of approximately $25 million was assumed to be available annually from Golden Gate Bridge tolls to fund GGBHTD's deficit. (Bridge projects receive first priority for these funds.) This maximum is exceeded consistently after the year 2000, at which time GGBHTD would need to consider raising tolls, reducing discounted tolls, or cutting service to continue operation and maintenance of the transit system.

Package A

The Package A cumulative 10-year cash positions for each operator are presented in Table 6. For the region, the cumulative 10-year deficit was estimated at $1.1 billion. Although MUNI accounted for the largest deficit position ($582 million, or 53 percent of the total), the table demonstrates the financial impact of the required transfers from Santa Clara and SamTrans to fund the CalTrain upgrade and downtown San Francisco extension. Specifically, the analysis led to the following findings and conclusions:

- CalTrain would require capital funding transfers of $365 million to fund capital enhancements and the local portion of its downtown extension. These transfers are in addition to the local operating and maintenance subsidy requirements.
- Funding all of the CalTrain projects included in Package A would increase the cumulative 10-year deficits for the three contributing operators, as follows:

		Deficit Impact ($ millions)	
Operator	*Transfer Payments ($ millions)*	*From*	*To*
MUNI	19	564	583
SCCTD	173	64	238
SamTrans	173	44	217
Total	365	692	1,038

- Despite the projected cumulative deficit, a comparison of replacement costs and expansion costs indicated that, between 1988 and 1997, there would be an opportunity to significantly extend the region's rail transit system. The analysis indicated that 63 percent of the region's capital replacement requirements are scheduled to occur in the 10 years beyond 1997. Similarly, 87 percent of the costs associated with the Package A rail extensions are projected to occur before 1997. After 1998, replacement costs would preempt the use of funds otherwise available for expansion.
- The region's cumulative deficit position could be attributed in part to recent cutbacks in federal and state funding for transit. As indicated earlier, the UMTA Section 9 program and the State Transportation Assistance (STA) program provided $67 million more to the region in 1984 than these fund-

TABLE 4 MTC PROPOSED PROJECT FUNDING ASSOCIATED WITH THE PENDING BART/SAMTRANS AGREEMENT (1987 DOLLARS, IN MILLIONS)

REVENUE SOURCE	PROJECT				TOTAL	PERCENT
	CALTRAIN EXTENSION	BART : S.F. AIRPORT	BART:WEST PITTSBURG	ALAMEDA COUNTY MEASURE B		
ALAMEDA COUNTY 1/2% SALES TAX				170.0	$ 170.0	8.2%
BART			34.0	58.0	92.0	4.4%
SAN MATEO SALES TAX - NEW 1/2% SALES TAX	169.0				169.0	8.2%
SAN MATEO SALES TAX - EXISTING SALES TAX		148.0	74.0	126.0	348.0	16.8%
SAN MATEO SALES TAX - EXISTING SALES TAX	173.0				173.0	8.4%
SAN FRANCISCO FUNDS						
SANTA CLARA COUNTY						
EXISTING BRIDGE TOLLS			9.0	15.0	24.0	1.2%
NEW BRIDGE TOLLS			56.0	94.0	150.0	7.3%
CONTRA COSTA COUNTY			178.0		178.0	8.6%
SUBTOTAL	**$342.0**	**$148.0**	**$351.0**	**$463.0**	**$1,304.0**	**63.1%**
STATE			74.0	126.0	200.0	9.7%
FEDERAL	109.0	442.0			551.0	26.6%
BALANCE				13.0	13.0	0.6%
TOTAL	**$451.0**	**$590.0**	**$425.0**	**$602.0**	**$2,068.0**	**100.0%**

TABLE 5 ENHANCED BASELINE CUMULATIVE 10-YEAR POSITION (MILLIONS OF DOLLARS, INFLATED)

LINE ITEM	OPERATOR								TOTAL
	AC TRANSIT	BART	CCCTA	CALTRAIN	GGBHTD	MUNI	SCCTD	SAMTRANS	
[1] Operations Revenue	1,489.4	2,302.4	156.2	351.0	442.9	2,594.9	1,781.6	853.6	9.972.0
[2] Operations Expenditures	1,416.3	2.208.0	149.4	351.0	442.9	2,726.3	1,612,7	537.1	9.443.7
OPERATIONS SURPLUS (DEFICIT)	73.1	94.4	6.8	0.0	0.0	(131.4)	168.9	316.5	528.3
[3] Capital Revenue	180.3	369.1	25.7	269.6	51.0	581.2	146.8	183.0	1,806.7
Capital Expenditures	180.3	476.4	25.7	268.9	53.9	1,049.7	185.8	183.0	2,423.7
CAPITAL SURPLUS (DEFICIT)	0.0	(107.3)	0.0	0.7	(2.9)	(468.5)	(39.0)	0.0	(617.0)
COMBINED SURPLUS (DEFICIT)	73.1	(12.9)	6.8	0.7	(2.9)	(599.9)	129.9	316.5	(88.7)
[4] **CUMULATIVE SURPLUS (DEFICIT)**	**4.0**	**92.2**	**1.3**	**0.0**	**0.0**	**(565.1)**	**284.8**	**267.0**	**84.9**
[5] Less: Transfers for Caltrain	0.0	0.0	0.0	(110.5)	0.0	5.5	52.5	52.5	0.0
CUMULATIVE SURPLUS (DEFICIT) without Caltrain Transfers	**4.0**	**92.2**	**1.3**	**(110.5)**	**0.0**	**(559.6)**	**337.3**	**319.5**	**84.9**

Note: Figures are approximate because interest, transfers, and capital revenue allocations have not been adjusted.

[1] Includes state operating subsidies of $24.4 million to Caltrain through 1991.

[2] Includes transfers from MUNI, SCCTD, and SamTrans to Caltrain for O&M (baseline and enhancements) and capital (baseline only) costs to eliminate any Caltrain deficits. Payments are made according to the following formula: MUNI 5.0%
SCCTD 47.5%
SamTrans 47.5%

[3] Includes transfers from operations.

[4] Cash position at the end of ten years (1997). The cumulative figure is the result of the ten year cash flow taking into account the operator's opening operating and capital balances.

[5] Transfers for capital only. Payments from SCCTD to Caltrain do not include an additional $11.5 million for ROW acquisition at Alma Station.

TABLE 6 PACKAGE A CUMULATIVE 10-YEAR POSITION (MILLIONS OF DOLLARS, INFLATED)

LINE ITEM	OPERATOR								TOTAL
	AC TRANSIT	BART	CCCTA	CALTRAIN	GGBHTD	MUNI	SCCTD	SAMTRANS	
[1] Operations Revenue	1,489.4	2,307.9	156.2	470.2	442.9	2,594.9	1,764.9	798.1	10,024.5
[2] Operations Expenditures	1,416.3	2,229.4	149.4	470.2	442.9	2,730.0	1675.2	572.2	9,685.6
OPERATIONS SURPLUS (DEFICIT)	73.1	78.5	6.8	0.0	0.0	(135.1)	89.7	225.9	338.9
[3] Capital Revenue	180.3	1,746.4	25.7	897.0	51.0	568.5	135.7	(25.0)	3,579.6
Capital Expenditures	180.3	1.929.9	25.7	896.3	53.9	1,050.7	535.2	192.3	4,864.3
CAPITAL SURPLUS (DEFICIT)	0.0	(183.5)	0.0	0.7	(2.9)	(482.2)	(399.5)	(217.3)	(1,284.7)
COMBINED SURPLUS (DEFICIT)	73.1	(105.0)	6.8	0.7	(2.9)	(617.3)	(309.8)	8.6	(945.8)
[4] **CUMULATIVE SURPLUS (DEFICIT)**	**4.0**	**(74.0)**	**1.3**	**0.0**	**0.0**	**(582.5)**	**(237.5)**	**(217.3)**	**(1,105.3)**
[5] Less: Transfers for Caltrain	0.0	0.0	0.0	(110.5)	0.0	5.5	52.5	52.5	0.0
[6] Less: Transfers for Downtown Extension	0.0	0.0	0.0	(254.5)	0.0	12.7	120.9	120.9	0.0
CUMULATIVE SURPLUS (DEFICIT) without Caltrain Transfers	**4.0**	**(74.0)**	**1.3**	**(365.0)**	**0.0**	**(564.3)**	**(64.1)**	**(43.9)**	**(1,105.3)**

Note: Figures are approximate because interest, transfers, and capital revenue allocations have not been adjusted.

[1] Figures are approximate because interest, transfers, and capital revenue allocations have not been adjusted.

[2] Includes state operating subsidies of $24.4 million to Caltrain through 1991.

[3] Includes transfers from MUNI, SCCTD, and SamTrans to Caltrain for O&M (baseline and enhancements) and capital (baseline only) costs to eliminate any Caltrain deficits. Payments are made according to the following formula:
MUNI 5.0%
SCCTD 47.5%
SamTrans 47.5%

[4] Includes transfers from operations.

[5] Cash position at the end of ten years (1997). The cumulative figure is the result of the ten year cash flow taking into account the operator's opening operating and capital balances.

[6] Capital transfers only. Payments from SCCTD to Caltrain do not include an additional $11.5 million for ROW acquisition at Alma station.

[7] Payments are made according to the following formula:
MUNI 5.0%
SCCTD 47.5%
SamTrans 47.5%

ing programs currently provide. If program funding had been maintained at 1984 levels, the cumulative 10-year deficit position under Package A would be cut in half.

Potential Actions To Ensure Funding

To address the funding shortfalls identified in the analyses, a series of potential actions was examined to determine if the enhanced baseline and Package A requirements could be met. The proposed actions were based on an increase in the state's participation in funding transit and on the passage of a half-cent sales tax measure in the county and city of San Francisco. (The other four urban counties are at the statutory maximum sales tax rate of 7 percent.) The following funding actions were proposed:

1. An additional half-cent sales tax for transit would be implemented in San Francisco County. It was assumed that 70 percent of all revenue generated from the additional sales tax would be dedicated to MUNI.
2. An additional state gas tax of 2 cents per gallon would be passed by the legislature to fund transit. Of the $250 million generated annually from this increase, dedications were assumed to be made as follows:
   - Approximately $111 million would be made available for CalTrain capital enhancements over the next 10 years.
   - The remaining $139 million would be allocated to rail operators to meet their capital requirements.
3. State sales tax revenues that result from any federal or state gasoline tax increase would be dedicated to transit. Each 1-cent gas tax increase would generate approximately $7 million in state sales tax revenues. Assuming a 10-cent gas tax increase (8 cents for highways and 2 cents for transit), the region's share of the resulting sales tax revenues would be $20 million to $25 million annually.
4. The analysis indicated that the region's total capital requirements would decline from $4.8 billion in the first 10 years (1988 through 1997) to $2.9 billion in the second 10 years (1998 through 2007), whereas sales tax revenues would increase steadily due to inflation as well as economic and population growth. Debt financing could therefore be used to fund construction of capital projects in the near term, using revenues anticipated over a longer period of time.

The potential impact of these actions on the region is presented in Table 7. By implementing this package of actions, it was found that the region's cumulative 10-year deficit of $1.1 billion could be reduced to $50 million.

Subsequent Actions Taken

Transportation funding issues raised in part by the Bay Area Transit Finance Plan received the attention of local officials

TABLE 7 SUMMARY OF EFFECT OF PROPOSED ACTIONS ON CUMULATIVE POSITION OF REGION—PACKAGE A (MILLIONS OF DOLLARS, INFLATED)

ACTION	NET IMPACT	CUMULATIVE DEFICIT
CUMULATIVE DEFICIT FOR PACKAGE A	------	1,105
SAN FRANCISCO 1/2-CENT SALES TAX INCREASE	280	825
TWO-CENT STATE GAS TAX INCREASE		
CALTRAIN CAPITAL ENHANCEMENTS	111	
ALLOCATIONS TO RAIL OPERATORS	639	
SUBTOTAL - GAS TAX INCREASE	750	355
SUBTOTAL - 1/2-CENT SALES & GAS TAX INCREASE	1,030	75
FUNDING FROM STATE SALES TAX ON GAS TAX INCREASE	25	50
TOTAL RESULT	**1,055**	**50**

and state legislators, and a number of actions have been taken to increase the level of funding for transit in the Bay Area. These actions are as follows:

- San Francisco rescinded proposed general fund budget cuts for MUNI in the FY 1989–1990 budget.
- San Francisco placed a countywide half-cent sales tax initiative on the November 1989 ballot, which was approved by the voters.
- The state will put an $18.5-billion revenue package (including $3 billion for transit) before the voters in June 1990 to vote on a 9-cent gas tax increase and a $1-billion general obligation bond issue.
- Legislation has passed extending the state's subsidy of CalTrain peninsula commute service through 1993.
- Santa Clara light-rail transit projects included in Package A have been incorporated into the Regional Rail Agreement, and proposed federal New Start funding was increased to 50 percent.
- A $28-million Section 3 New Start earmark has been included in the FY 1990 UMTA appropriations bill.

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Transit Capital Planning in the San Francisco Bay Area

JOEL MARKOWITZ

In the San Francisco Bay area, the multiplicity of independent public transit agencies complicates transit capital planning. Throughout the 1980s, the Metropolitan Transportation Commission (MTC), the regional transportation planning agency, coordinated a cooperative process to produce a list of priorities for federal capital grants. The process evolved into a complex but subjective scoring and ranking system, within a fund constraint. Two observations emerged after a decade of experience: (a) the process could continue despite annual reductions in federal and state capital financing, and (b) inherent limitations in the subjective scoring system prevented it from fully incorporating diverse capital program goals and needs. A resilient institutional framework has contributed to the successful continuation and refinement of the process.

The San Francisco Bay area is blessed with spectacular scenery, a moderate climate, unmatched cultural diversity, and a vibrant economy. It is also home to perhaps the most diverse public transportation system in North America. Transit service is provided by 17 principal public agencies, not including exclusive paratransit services, and almost as many modes. A map of the location of the area's major transit operators is shown in Figure 1, and a list of transit operator statistics is presented in Table 1.

Although this diversity serves the patron well, it presents formidable problems for coordinated planning. Since 1971, the Metropolitan Transportation Commission (MTC) has been responsible for overall transportation planning in the nine-county San Francisco Bay area. MTC has 16 voting members, of which 14 are appointed by the boards of supervisors and councils of mayors within each county, and 2 represent other regional agencies.

MTC is one of the two statutorily created transportation planning agencies in the state of California. It was charged with developing and updating a regional transportation plan and was given review authority over all applications for federal and state transportation grants within its jurisdiction.

Since 1978, MTC has worked formally with the largest transit agencies in the region through an advisory committee called the Transit Operator Coordinating Council (TOCC). TOCC comprises the general managers of the eight largest systems: Alameda-Contra Costa Transit (AC Transit), Bay Area Rapid Transit (BART), Central Contra Costa Transit (CCCTA), California Department of Transportation (operator of the CalTrain peninsula commute train), Golden Gate Transit (GGBHTD), San Francisco Municipal Railway (MUNI), San Mateo County Transit (SamTrans), and Santa Clara County Transit (SCCTD). Representatives of the transit services in the cities of Vallejo and Santa Rosa are also included. TOCC has been MTC's forum for developing regional policies, resolving differences, and promoting coordination.

As public transportation financing changed over the years, so did MTC's role. In 1972, the Transportation Development Act (TDA) was enacted by the state legislature. The TDA created local transportation funds in each county on the basis of a quarter-cent of the state sales tax. As administrator of this fund source within the region, MTC is responsible for allocating about $180 million annually to transit operators and local governments. Because the funds must remain within each county, MTC must decide among claimants in cases for which more than one agency serves the same geographic area. TDA funds are predominantly used for operating expenses by the principal public transit operators.

Under federal law, MTC was named the metropolitan planning organization (MPO) for carrying out planning guidelines and administrative regulations of FHWA and UMTA. For instance, MTC is responsible for preparing the annual update to the multiyear Transportation Improvement Program (TIP), the basis for all subsequent federal transportation grant applications.

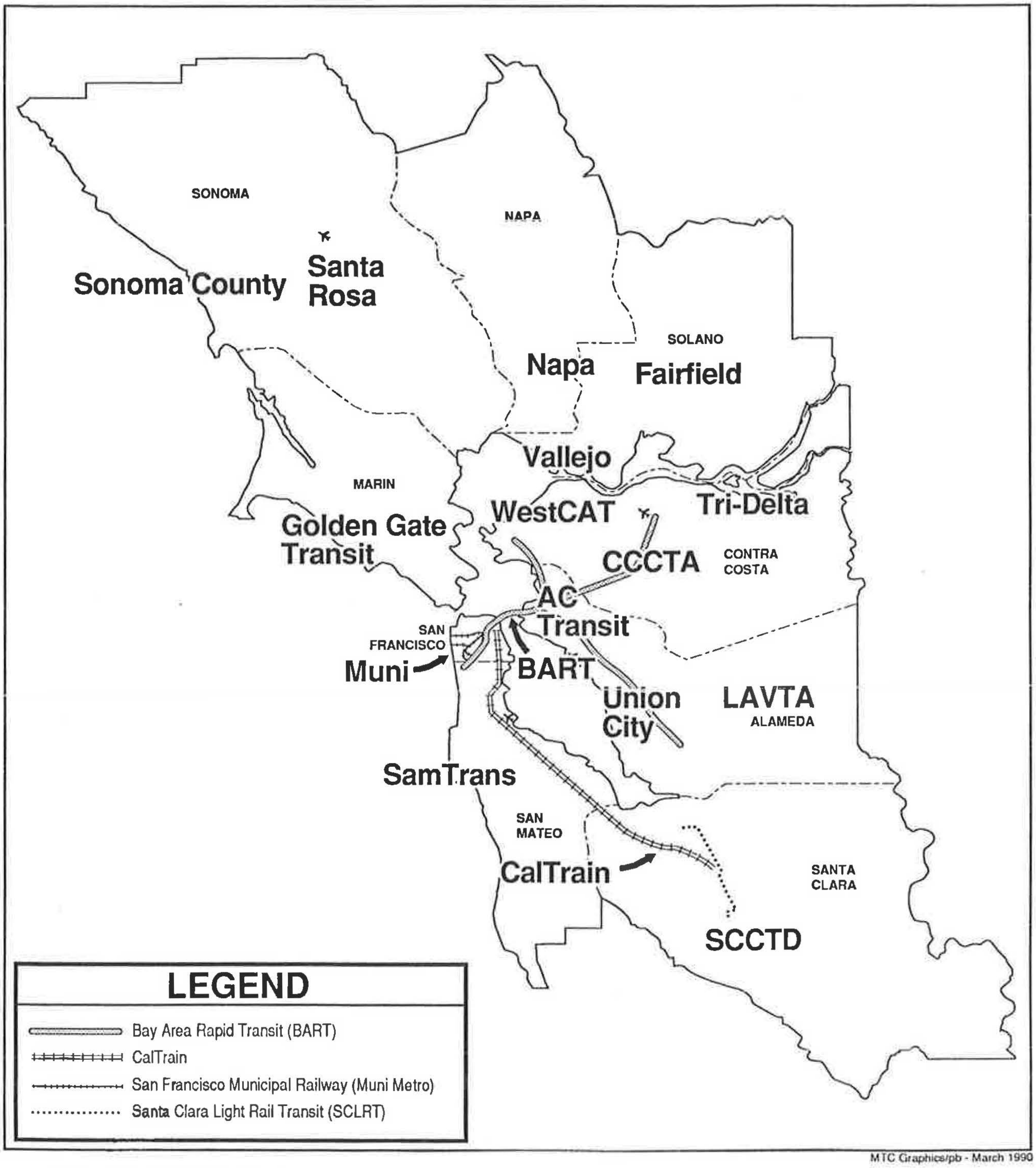
When the federal transit block grant program (Section 9) was adopted in 1982, MTC was made the designated recipient for those funds within the two major urbanized areas under its jurisdiction: San Francisco/Oakland (encompassing parts of five counties) and San Jose (within one county).

Urbanized areas are specially defined by the U.S. Census Bureau and have little relation to city or county boundaries or metropolitan statistical areas (MSAs). In the San Francisco/Oakland urbanized area, there are at least six discontiguous areas of urban density, separated by water or hills. These definitions were established to implement UMTA's first formula program under Section 5. When Section 9 replaced Section 5 in 1982, the formula was changed substantially but the definitions of urbanized areas were maintained.

As designated recipient, MTC is responsible for programming all Section 9 operating and capital funds for the urbanized areas each year. In FY 1989–1990, these funds were expected to be about $90 million.

Section 9 funds must remain within the urbanized areas as apportioned by UMTA. There are eight eligible recipients in the San Francisco/Oakland urbanized area and two in the San Jose area, and one operator crosses between the two areas. It was largely in response to the need to divide the Section 9 pie each year that the region's approach to capital replacement planning was developed.

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



MTC Graphics/pb - March 1990

FIGURE 1 Bay area transit operators.

EVOLUTION OF THE CAPITAL PRIORITIES PROCESS

Overview of the Process

Figure 2 shows the overall capital priorities process. Each year, a review of the previous year's process is conducted to develop new recommendations, which must be formally adopted by MTC in the fall. In January, the operators submit their proposals for the upcoming 5-year period, including projects for the new fifth year, and any amendments to the first 4 years. From January through April, MTC staff evaluate the proposals under the adopted criteria, propose project scores for review by operators, and recommend a final ranking. The final 5-year priority list is adopted by MTC in May as the basis for subsequent preparation of the TIP in June and the Section 9 Program of Projects and operators' individual grant applications during the summer. The adopted program deter-

TABLE 1 TRANSIT OPERATOR STATISTICS: OPERATING BUDGETS 1987–1988 (a)

	Operating Data		Sources of Operating Funds (b) ($000)							
			Local/Regional				State	Federal		
Transit Operator	Active Fleet	Average Weekday Boardings	User (Fares)	Local Taxes	TDA (c)	AB 1107 (d)	STA (e)	UMTA (f)	Other (g)	Total Operating Expenses ($000)
AC Transit (h)	850	211,000	$ 30,124	$ 27,594	$ 25,315	$ 15,238	$ 943	$ 7,073	$ 7,610	$ 113,897
BART	526	202,500	78,475	76,084	348	0	564	0	5,221	160,692
Caltrans	73	16,000	9,545	0	3,788 (j)	0	0	1,272	11,347	25,952
CCCTA	95	14,300	1,719	0	7,949	0	0	1,411	-409	10,670
ECCTA	23	1,800	171	0	1,581	0	0	0	-18	1,734
Fairfield	10	1,100	114	0	306	0	0	255	-39	636
GGBHTD	243 (I)	30,400	14,444	587	6,817	0	31	1,754	14,096	37,729
LAVTA	22	1,500	126	0	2,007	0	0	0	122	2,255
Napa City	9	1,600	130	0	296	0	0	289	-9	706
SF Muni	1,065	801,200	71,176	115,656	17,056	15,238	575	8,764	7,834	236,299
SamTrans	299	61,500	7,797	13,079	11,563	0	8	1,636	460	34,543
SCCTD	552	118,500	11,338	56,585	34,313	0	0	6,983	-571	108,648
Santa Rosa	21	4,200	503	0	1,236	0	35	553	-66	2,261
Sonoma County	35	2,800	541	0	2,113	0	65	0	-4	2,715
Union City	8	1,400	145	0	984(k)	0	0	204(k)	-319	1,014
Vallejo	31	4,400	555	0	1,215	0	251	213	-127	2,107
WCCCTA	17	1,000	87	0	868	0	0	224(k)	-243	936
Regional Total	3,879	1,475,200	$226,990	$289,585	$117,755	$ 30,476	$ 2,472	$ 30,631	$ 44,885	$ 742,794

(a) Figures are unaudited data reported by transit operating agencies and MTC resolutions.

(b) TDA, STA, AB 1107 and UMTA funds corresponds to MTC allocations. Actual amount used for the fiscal year might have varied somewhat. Any adjustments are made under "Other."

(c) Transportation Development Act.

(d) 25% of 1/2 cent transactions and sales tax revenues collected in Alameda, Contra Costa and San Francisco counties.

(e) State Transit Assistance.

(f) Urban Mass Transportation Administration grants (Sections 9 and 18). Actual amounts were reduced 8.43% after appropriations bill was signed.

(g) Negative numbers indicate funding not actually spent for operations in FY 1987-88.

(h) AC Transit Districts 1, 2 and contract services, but excluding BART express bus services.

(i) In addition, service is provided by 19 club buses.

(j) Allocations to SF Muni and SamTrans for CalTrain services.

(k) Includes allocations to AC Transit for contract services to WestCat and Union City.

mines both the division of Section 9 formula block grant funds and the regional program for seeking federal and state discretionary funds. All operators agree to work with MTC in Sacramento and Washington to promote not only their own projects but the entire regional program.

The current process was developed through several stages, with each step adding further refinements. A review of the historical development of the process is provided in the following subsections, followed by a discussion of the institutional arrangements that maintain the effectiveness of the process.

Before Section 9

Other than the Section 5 Tier IV bus capital program, which was apportioned by formula to urbanized areas for vehicle purchases, other transit capital needs were previously met by UMTA's Section 3 discretionary program. Although it was possible to estimate the amount of Section 3 money that could be expected each year, these funds were not guaranteed.

Consequently, long lists of projects were developed, and there were always unmet needs from the previous year that had to be added to the new year's list. MTC tried to introduce some flexibility by defining a 2-year program, so adjustments could be made when UMTA's discretionary program choices were made, but true multiyear programming was not attempted. Although a 5-year program was defined, only the first year's needs were explicit. All other projects were placed in the out-years list. Moreover, evaluation criteria were generally nonspecific.

All projects had to meet the following general criteria, which were principally procedural requirements:

- Local consensus, including approval by the policy board, community support, and inclusion in the Short-Range Transit Plan (SRTP);
- Regional requirements, i.e., conformity with MTC's Regional Transportation Plan and rail proposals resulting from corridor or other special studies; and
- Sound financial plans, including sources and amounts for capital and associated operating costs.

Priority consideration was given to projects that (a) enhanced and supported desired development patterns, (b) were well defined and ready for implementation, and (c) were likely to compete well for funding from major sources (i.e., state and federal).

Other criteria were defined for each of the three funding categories—Section 5 bus, Section 3 bus facilities, and Section

1.	Agree on procedures and criteria	October
2.	Operators develop and submit 5-year program documentation	December-January
3.	MTC staff develop 5-year Master rankings by: Screening all projects for necessary findings Evaluating and ranking by general and project merit criteria	February-March
4.	MTC staff propose tentative programming of ranked projects for Section 3, Section 9, mixed Section 3/9, or special funding	March
5.	MTC staff develops 5-year programs for Section 9 and Section 3 projects. Projects will be ranked within the 5-year Section 9 or Section 3 programs based on rankings developed in Step 3.	April
6.	MTC and operators discuss final project rankings and assignments to fund categories	April
7.	Present priorities to MTC's Work Program and Plan Revision Committee (PW&PRC)	May
8.	Present priorities for Commission adoption	May
9.	If necessary, re-open TOCC discussion of programming of projects based upon final federal and state budget or appropriation actions.	(as needed)
10.	Develop TIP, Program of Projects, and Guideway Plan by refining documentation submitted for priority-setting.	June-October

FIGURE 2 **Steps in the capital priorities process.**

3 rail modernization. For Section 5 bus, a replacement program was implemented on the basis of fleet age using a formula. For bus facilities and rail modernization, projects were ranked in descending order depending on whether they were required for improving safety or reliability, maintaining the existing plant and services, or expanding service. There were no explicit evaluations of individual projects within the three categories, although operators were asked to indicate their own priority order for their projects.

This approach produced a list of recommended projects for each transit operator under each funding category, but there was no predetermined interoperator project ranking. As federal funding was determined, adjustments were made on an ad hoc basis.

Early Revisions Under Section 9

At first, Section 9 was simply viewed as a more predictable and flexible Section 5 program. The same kinds of criteria were applied as before, only within the new categories of Sections 9 and 3 funding. The program was still a 1-year list of projects, grouped by operator in the priority order submitted, subject only to reranking as safety, maintenance (including productivity improvements as well as replacement), or expansion, in that order. The general criteria described previously were still applied.

By 1984, 2 years into the Section 9 program, it became clear that the annual block grants allowed a new degree of flexible multiyear planning that could be advantageous to all. Although the annual appropriations process was still subject to uncertainty, the multiyear congressional authorizations (maximums) allowed the region to better predict a reasonable range of available resources. Consequently, the procedures and criteria for the 5-year program were substantially revised, beginning with FY 1985–1986.

The first major change was the development of more explicit regional objectives for the capital priority-setting process. Six objectives were adopted:

1. Fund basic capital requirements to sustain and improve the existing transit capital plant;
2. Use evaluation criteria that make the process more predictable for the operators, avoiding rigid, arbitrary, or mechanical use of the criteria;
3. Honor the operators' own priorities as much as possible to reinforce their 5-year planning;
4. Maintain the region's credibility with state and federal funding agencies by demonstrating the soundness and validity of the process;
5. Tailor the project evaluations to the projects' significance by not requiring elaborate evaluation of routine projects (basic needs) and by focusing on the few large or special projects (nonbasic) to be funded at the margin each year; and
6. Test the resulting priorities for their fairness to all operators given the total funding available to them, the services provided, or other relevant factors.

Although these objectives were more explicit than before, they were quite ambiguous on major points, which was partly a result of the process of negotiation that occurs continually among MTC and the transit operators.

In addition to the objectives, the procedures included several other changes:

- A more explicit process (see Figure 2);
- A new documentation format, requiring annual phasing of multiyear projects to be shown explicitly, along with year-by-year operator rankings;
- A requirement for project justification worksheets for each project requested in the annual element (the first year of the new 5-year program);
- Expanded evaluation criteria with explicit, project-by-project scores and ranks (see Figure 3); and
- Explicit programming of each of the 5 years in the program and restrictive rules on subsequent amendments.

The scoring and ranking were crude—mostly a matter of assigning points if individual criteria were met, with some weighting across criteria. The basic/nonbasic distinction was maintained, so there were in effect two lists for each year. The operator's own project ranking was deemphasized but was still worth some points in the scoring scheme. The "honor operator priorities" objective was replaced with "establish priorities on the basis of the region's adopted criteria and each operator's 5-year planning process." Still, the principle of explicit scores and rankings was established.

Later Revisions

The revisions were reviewed the next year, and the following additional changes were instituted:

- Uniform regional scoring replaced any acknowledgment of operator priorities (see Figure 4).
- The basic/nonbasic distinction was dropped in favor of a master list that incorporated all types of projects in score order.
- The programs for each of the 5 years were constrained to a more reasonable fund estimate rather than programming to the fully authorized level (recognizing that appropriations never match authorizations).

The new scoring process was as subjective as before but was more focused, with four major areas for assessing project merit: direct passenger benefits, system productivity and efficiency benefits, regional goals, and sustaining the capital plant. A scoring scheme was developed for the four criteria with high receiving 10 points, medium receiving 5 points, and low receiving 1 point. This scheme was admittedly arbitrary but was simple and intuitive enough to gain broad acceptance.

Subsequent annual reevaluations have refined the process. More gradations in allocating points to projects were instituted (see Figure 5), and more explicit guidelines for point assignments were developed (see Figure 6). Standard inflation rates and bus prices were developed and are presented in Table 2. The basic process, however, has remained unchanged over four annual cycles.

INSTITUTIONAL CONSIDERATIONS

In capital priority setting, MTC's overriding objective has been to ensure that the region is able to bring in and effectively spend federal and state transportation funding to sustain and expand the region's transit system. To achieve that goal, it was essential that the region's many operators work together to present a single capital program to federal and state funding authorities. Before the previously described process was adopted, operator disagreements frequently carried over into the political arena or caused conflicting lobbying with the funding agencies. A process to forestall such detrimental results needed several characteristics, which are described in the following subsections.

Credibility

Credibility was considered the primary feature of the process. The participants had to believe that the process was honest, open, predictable, and competently run. MTC sought to achieve credibility by involving the operators at every stage—from the review of procedures and fund estimates to the debate over individual project scoring. MTC staff worksheets were available to anyone questioning the scoring, and projects were often rescored following a challenge if mistakes or incomplete data were discovered. No changes were made without a full explanation and the opportunity for debate by all participants. There were no subsidiary transactions. Any such attempt would have undercut the needed consensus on the overall capital program. The fundamental test of credibility is the agreement by all operators that the overall result is fair even if their individual requests are not all granted.

On a technical level, the scoring system appears to be deficient. It is inherently subjective, and the point assignments

Where possible and reasonable, quantitative evaluations of project merit should be provided. Otherwise, concise verbal descriptions are acceptable. Criteria should be applied to a project only if appropriate to the project's scope and intended fund source. Criteria are _not_ listed in priority order.

			WEIGHTS
	A.	General	
	1.	Project enhances and supports desired development patterns	1
	2.	Project likely to compete well for funding from major sources	1
	3.	Project was high-priority but unfunded in previous Transit Capital Priorities	2
	4.	Project is a continuation of a multi-year project previously given high-priority	2
(B)	5.	Project responds to specific recommendations of special studies or performance audits	2
	6.	Project implements specific, previously committed service expansions in accordance with adopted plans and programs.	1
(B)	7.	If replacement or rehabilitation, part of a well-defined program containing specific age, wear or other criteria governing the replacement schedule.	1
	B.	Project Need	
	1.	Well-defined purpose, objective	2
	2.	Adverse effects if project deferred or deleted	1
	3.	No suitable alternative action or project	1
	4.	Project is ranked highly by operator	2
	C.	Project Effectiveness	
	1.	Clear statement of project benefits to system operations, passengers, local/regional goals, etc.	1
(B)	2.	Essential to continue normal operations	4
(B)	3.	Addresses significant system safety or passenger/employee security problems	2
(B)	4.	Increases productivity of system or addresses significant productivity problems (reduces cost, increases efficiency or effectiveness)	2
(B)	5.	Required to sustain or improve existing plant	4
	6.	Increases system capacity to meet current and projected demand.	1
	D.	Adequacy of Financial Plan	
(B)	1.	Financial plan indicates all sources of funds for the project	2
	2.	Shows local commitment or private participation, where appropriate	1
	3.	Shows sources and amounts of operating funds required to implement proposed capital project	1
(B)		Reasonable cost estimates, phasing, cash flow	2

FIGURE 3 Criteria for evaluating project merit.

I. NECESSARY FINDINGS

All projects must be in conformance with the following criteria before an evaluation (II below) will be made. (Criteria are not in any order of importance.)

A. Regional Requirements

1.* Approval by operator policy board.

2.* Included in upcoming 5-year Short Range Transit Development Plan (SRTP).

3. Project is advanced to a state of readiness for implementation in the year indicated.

4.* Project is well-defined and justified.

5. Project implementation schedule provides for any necessary clearances and approvals.

6.* Operator has capacity to implement project.

7. Operator has an adequate financial plan, with reasonable cost estimates, phasing, and cash flow, and all sources of expected funding identified.

* For projects programmed in out years (years 2-5), only requirements 1, 2, 4 and 6 apply.

II. PROJECT EVALUATION

Where possible and reasonable, quantitative evaluations of project merit should be provided to allow gradations in scoring to be made.

	SCORES
A. Continuation of Prior Commitment	
1. Project is a continuation of a funded multi-year project previously given high priority *and* the operator continues to assign the project high priority.	10

B. Project Merit	High	Medium/ Average	Low
1. The degree to which the project directly benefits the passengers	10	5	1
2. The degree to which the project directly produces benefits to system productivity and efficiency.	10	5	1
3. The degree to which the project directly addresses significant or regional goals or policies (e.g., E&H accessibility or regional coordination).	10	5	1
4. Replacement or rehabilitation for maintaining existing service.	10	5	1

1. Direct Passenger Benefits - direct on-street service effects (schedule adherence, safety, reliability, etc.), service quality (peak capacity), passenger comfort (clean vehicles, shelters, etc.), passenger convenience (public information, fare payment, access, etc.).

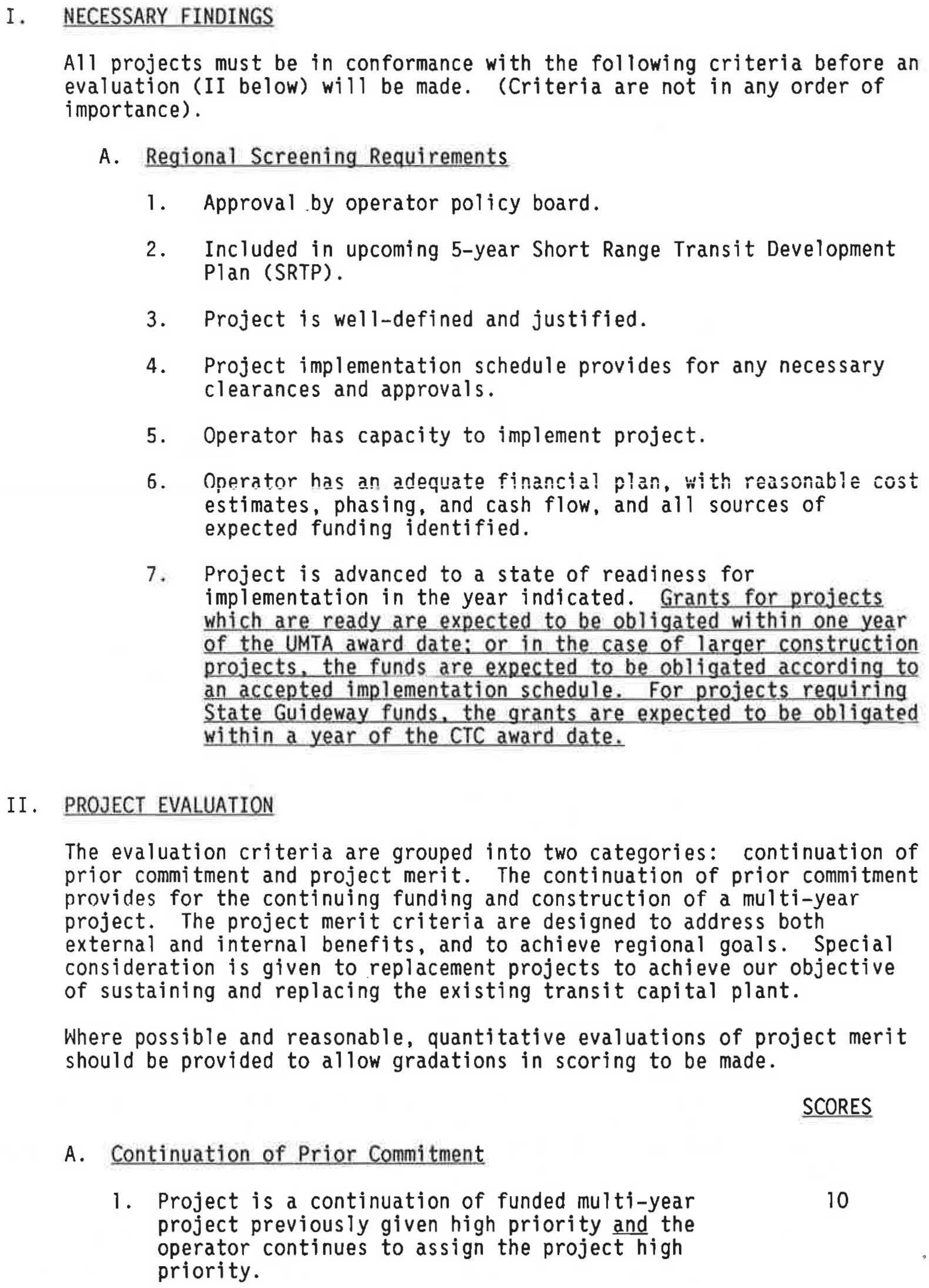
2. System Productivity - direct reductions in cost or achievement of efficiencies in operations or maintenance, revenue enhancement, etc.

3. Regional Goals - E&H access; interoperator schedule, fare and transfer coordination.

FIGURE 4 Evaluation criteria and scoring.

are arranged on an arbitrary scale that has no clear scientific basis. Still, the approach is simple enough that all participants can grasp it. A more complex scheme would tend to favor certain types of projects or modes and thereby threaten the consensus. It is not possible to obtain equally quantitative, objective data on every type of project to assess engineering costs and benefits. In effect, the simplicity of the process is a source of credibility.

However, merely satisfying everyone within the region is not enough to ensure funding by the state and federal agencies. Credibility also means that the priorities must reflect real needs, not just mutual back scratching. In 1981, MTC published its first evaluation of long-term transit capital replacement needs (*1*). In rough terms, that report identified a need for about $100 million annually for basic capital replacement, notwithstanding additional needs for system expansion. Because the Section 9 formula apportionment to the Bay Area was initially in that range, MTC decided that sustaining the existing capital plant had to receive top priority in terms of the new formula funds. MTC wanted to ensure that the region



I. NECESSARY FINDINGS

All projects must be in conformance with the following criteria before an evaluation (II below) will be made. (Criteria are not in any order of importance).

A. Regional Screening Requirements

1. Approval by operator policy board.
2. Included in upcoming 5-year Short Range Transit Development Plan (SRTP).
3. Project is well-defined and justified.
4. Project implementation schedule provides for any necessary clearances and approvals.
5. Operator has capacity to implement project.
6. Operator has an adequate financial plan, with reasonable cost estimates, phasing, and cash flow, and all sources of expected funding identified.
7. Project is advanced to a state of readiness for implementation in the year indicated. Grants for projects which are ready are expected to be obligated within one year of the UMTA award date; or in the case of larger construction projects, the funds are expected to be obligated according to an accepted implementation schedule. For projects requiring State Guideway funds, the grants are expected to be obligated within a year of the CTC award date.

II. PROJECT EVALUATION

The evaluation criteria are grouped into two categories: continuation of prior commitment and project merit. The continuation of prior commitment provides for the continuing funding and construction of a multi-year project. The project merit criteria are designed to address both external and internal benefits, and to achieve regional goals. Special consideration is given to replacement projects to achieve our objective of sustaining and replacing the existing transit capital plant.

Where possible and reasonable, quantitative evaluations of project merit should be provided to allow gradations in scoring to be made.

	SCORES
A. Continuation of Prior Commitment	
1. Project is a continuation of funded multi-year project previously given high priority and the operator continues to assign the project high priority.	10

FIGURE 5 Evaluation criteria and scoring (refined). (*continued on next page*)

B. Project Merit	High	High/ Medium	Medium	Low/ Medium	Low
1. The degree to which the project directly benefits the passengers	10	6	5	4	1

Direct Passenger Benefits - direct on-street service effects (schedule adherence, safety, reliability, etc.), service-quality (peak capacity), passenger comfort (clean vehicles, shelters, etc.), passenger convenience (public information, fare payment, access, etc.).

2. The degree to which the project directly produces benefits to internal system productivity and efficiency	10	6	5	4	1

Internal System productivity - direct reductions in cost or achievement of efficiencies in operations or maintenance, revenue enhancement, etc.

3. The degree to which the project directly addresses significant or regional goals or policies	10	6	5	4	1

Regional Goals - E&H access; interoperator schedule, fare and transfer coordination.

4. Replacement or rehabilitation for maintaining existing service.	10	6	5	4	1

Replacement or Rehabilitation - MTC staff and operators will develop guidelines for scoring different types of replacement projects.

FIGURE 5 ***(continued from previous page)***

did not suffer the fate of some older urban areas that had deferred basic maintenance but were later faced with a near collapse of their infrastructure. A dogged commitment to a clear goal—maintain the plant first and expand later—helped establish the external credibility of the process.

Responsiveness

It is easy to say, "Here are the rules; follow them and don't deviate." In the real-world environment, however, such procedural purity is dysfunctional. Emergencies and gradually changing conditions may demand radical reevaluation of priorities. Nothing requires such a reevaluation so quickly as changes in funding programs, levels, and rules. The process has had to deal with frequent changes over the years, particularly the drastic reductions in state and federal funding levels (see Figures 7 and 8). Changes in the fund estimates meant that the line separating funded from unfunded projects had to be redrawn and the priority order rules had to be revised.

Most operators have had to request amendments in their plans to accommodate some unanticipated event. For example, a project is over budget and needs additional resources, a project is under budget and previously unfunded projects are on the list, a project is running into environmental clearance problems with toxic wastes, or a project has to be cut because it is not well defined and ready to implement. For each request, the operators know they must be both accommodating and skeptical so that the process works equitably no matter which side of the fence they are on.

Self-Enforcement

The process would not have survived one cycle if it had depended on MTC staff to police it. Instead, a Capital Priorities Task Force was established, chaired by one of the operator members, to oversee the process. MTC staff members support the task force, but their role is limited to the following:

- Keep the process on schedule.
- Maintain the integrity of the process.
- Make sure no operator gains an unfair advantage.
- Keep the lines of communication open.

Once the task force agrees on the ground rules, the individual members have an incentive to police themselves. Because the amount of funding can be estimated in advance (at least for Section 9), there is a zero-sum game. In other words, it

TABLE 2 BUS PRICES

	Artic 60'	Super Bus 40'	Std 40'	35'	30'	24 Psgr	Van
FY 1990	$300,000	$231,525	$189,630	$185,000	$180,000	$61,320	$35,700
FY 1991	315,000	243,101	199,112	194,250	189,000	64,386	37,485
FY 1992	330,750	255,256	209,067	203,963	198,450	67,605	39,359
FY 1993	347,288	268,019	219,520	214,161	208,373	70,986	41,327
FY 1994	364,652	281,420	230,496	224,869	218,791	74,535	43,394
FY 1995	382,884	295,491	242,021	236,112	229,731	78,262	45,563
FY 1996	402,029	310,266	254,122	247,918	241,217	82,175	47,841
FY 1997	422,130	352,779	266,828	260,314	253,278	86,283	50,233
FY 1988	443,237	342,068	280,170	273,329	265,942	90,598	52,745
FY 1999	465,398	359,171	294,178	286,996	279,239	95,127	55,382
FY 2000	488,668	377,130	308,887	301,346	293,201	99,884	58,152

Assumptions:

- 5.0% Inflation Rate
- Bus prices include: administration and inspection costs, air conditioning, delivery charge, electronic destination signs, padded seats, radios, registering fareboxes, roof exhaust exits, sales tax, spare power packs, warranty extension, wheelchair lifts. (Normal "bus spec development" included in administration and inspection costs.)

CRITERION B.1

Degree to which the project directly benefits the passengers.

The following elements are used in the scoring of this criteria;

1. Majority of that mode benefits - H
2. Safety - L,H
3. Reliability - L, H
4. Peak Capacity/Increase in Service, L,H
5. Comfort and Convenience - L,H

Score 10 = Majority of that mode benefits + High Safety or High Reliability

6 = (H,L,L) or (H,H) or (L,L,L,L)
5 = (L,L,L) or (L,H)
4 = (L,L) or (H,)
1 = L

e.g. If the project directly benefits the passengers and has High Safety and High Reliability it receives a score of 6.

- Replacement buses receive a score of 4.

- Expansion buses receive a score of 5.

- Park-and-Ride facilities receive a score of 6.

- Other parking facilities receive a score of 5.

This criterion does not apply to MIS or Maintenance Facilities.

CRITERION B.2

Degree to which the project directly produces benefits to system productivity and efficiency.

The following is used in the scoring of this criteria;

1. Cost reduction/efficiency of operations (including administration)/maintenance and revenue enhancement.

Score 10 = H
6 = M+
5 = M
4 = M-
1 = L (Low efficiency or service effectiveness)

a. All normal replacement receives a score of 4.

b. Normally Maintenance Facilities and support equipment receive a score of 4.

c. Expansion buses receive a score of 1.

d. Park-and-Ride facilities receive a score of 1.

e. Other parking facilities receive a score of 1.

CRITERION B.3

Degree to which the project directly addresses significant regional goals or policies.

a. Replacement of accessible with accessible vehicles a score of 0.

FIGURE 6 Guidelines for scoring projects. ***(continued on next page)***

b. Replacement of non-accessible vehicles with accessible vehicles receive a score of 1.

c. Lift replacement receive a score of 1.

d. Expansion buses receive a score of 1.

e. Other accessible projects may receive 1, 4, 5, 6 or 10.

f. Coordination projects, with an accessibility element, may receive a total score of 1, 4, 5, 6 or 10.

CRITERION B.4

Replacement or rehabilitation for maintaining existing service.

5 points -	for buses aged 12 and above. An additional point will be given, if the operator has an established replacement program which is well-defined, documented and includes factors governing the replacement schedule.
20 points -	the justification clearly demonstrates special circumstances (age, maintenance cost or other factors) which make replacement an urgent priority.

FIGURE 6 *(continued from previous page)*

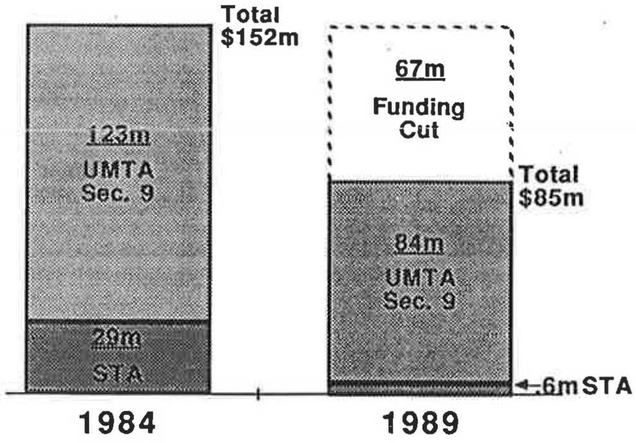


FIGURE 7 Recent cuts in federal and state funds to the Bay area ($ millions).

is in each player's interest to make sure the other players do not receive more funds than the rules allow.

In addition to the external enforcement, internal MTC staffing has developed into roles that foster open debate on capital-project evaluations. An MTC staff member is assigned to each operator on a continuing basis, functioning as the MTC expert for that operator's planning program, operations, and capital needs. These staff act as both critics and advocates for the operators. They take the first step in assigning scores to projects; then, to ensure consistency and fairness, they argue for those scores with the staff representing other operators. If necessary, an MTC staff member who is not assigned to a particular operator serves as mediator and referee. Through this internal process, major problems are identified and options developed before the task force considers the remaining issues.

Reinforcement

The capital priorities process can serve to reinforce both regional and operator needs. It was not designed to be a special MTC event apart from each operator's ongoing concerns. Rather, it was meant to be an outgrowth of every operator's continuing planning process. The MTC requirements help the operators promote better multiyear capital planning internally, which results in better individual short-range plans and, in turn, a more sound regional plan. Improvements in operator planning helped provide the basic data for the recently completed *Bay Area Transit Finance Plan* (*2*), a long-term look at the region's ability both to maintain the existing system and fund needed expansions.

Feasibility

Implementation is the hobgoblin of all good ideas. A regional capital priorities process was a good idea, but implementing it has taken years of trial and error. MTC did not want to impose an overly burdensome bureaucratic requirement on the operators, considering the myriad requirements of the federal and state funding agencies. Yet, a lot of new information was being demanded in a short timeframe.

A partial solution to this dilemma was to ease the paperwork preparation and reduce the processing time through automation. MTC began to apply microcomputers to this process in the early 1980s (*3*). Operators currently prepare their 5-year program financial summaries on electronic spreadsheets. MTC supplies the disks with blank forms, and the operators fill in the blanks on the computer screen (see Tables 3–5). Formulas incorporating inflation adjustments are provided. When the disks are returned to MTC, the individual operator files can be easily sorted and combined into

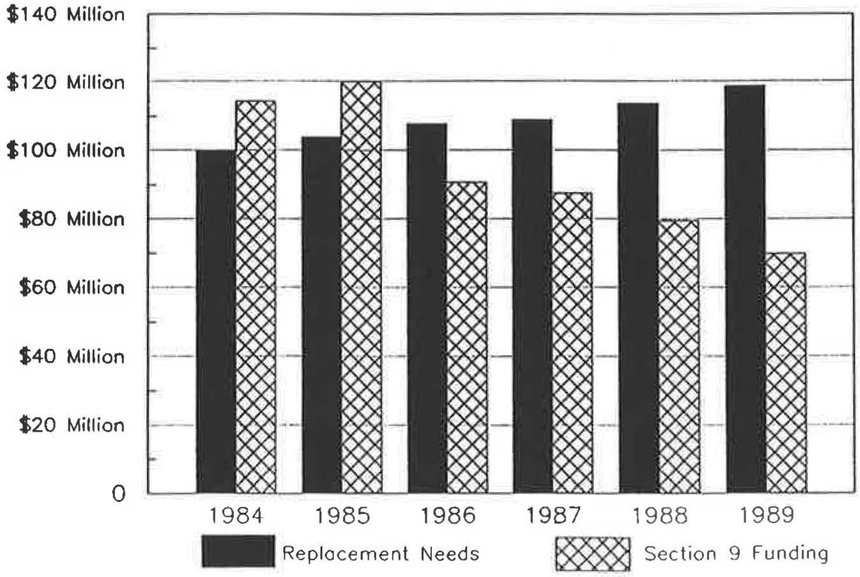


FIGURE 8 Transit capital replacement needs versus funding.

the regional program. Once on disk, the draft priorities can be revised quickly to respond to changes in project scope or available funding. For example, when the federal deficit reduction cuts began (Gramm-Rudman-Hollings), having the priorities on disk allowed the task force to briefly consider several options in terms of scaling back projects or phasing them over longer periods.

In addition to the quantitative information, operators are also given blank word processing forms on disk to help them fill out the project justification worksheets required for first-year projects (see Figure 9). The standard format allows easier compilation of programs into the regional program of projects document required by UMTA.

This relatively low level of automation has greatly improved the process. The production demands of assembling the multiyear program have been drastically reduced, and a variety of options can now be examined in a short time. This ability to respond quickly to changes requested by the task force and TOCC has further enhanced the effectiveness of the process.

CONTINUING ISSUES

No planning process is ever completed. Experience with capital priority setting over the past several years has revealed shortcomings that may be inherent in such a process.

Project Selection

It is difficult to determine if the best projects are being presented. Although MTC can adopt the rules, each operator's internal process actually regulates the individual projects that feed into the pipeline. Only the operator can thoroughly evaluate the actions needed to sustain its capital plant. There is little MTC can do directly to influence the method each operator uses to ensure that the most important projects are put forward.

Scoring

Another issue that must be considered is the effectiveness of the scoring scheme. The simple high, medium, and low scores for four equally weighted criteria may be unintentionally distorting the priorities. Small projects tend to score low because of the relative magnitude of their impact on any criterion. Facilities projects tend to score lower than vehicle projects because the facilities projects rarely score well under the direct passenger benefits criterion.

Different remedies are possible, but all have their problems. If the list of criteria is expanded, different weighting must immediately be justified. For instance, a new procedure developed in Philadelphia has 12 criteria, scored on a scale of 0 to 4, with weights for each criterion from 3 to 10 (*4*). Although it is possible to determine such weightings through a more rigorous analysis (e.g., preferences of informed experts), the relative weighting can never be settled conclusively.

Another frequently proposed solution is to provide a portion of the Section 9 block grant to each operator by formula to fund all the smaller projects that will never score high enough under regional criteria to make the annual funding cut. Although this solution is being reconsidered, a formula approach could undercut the basic philosophy of directing funds to the best projects in the region. Any formula would invariably direct too much or too little to some operators, leaving higher priority needs unmet.

Project Cutbacks

The appropriateness of the project cutbacks must also be evaluated. Once a capital priority list is completed, it is subject to radical revision if the final appropriation level and apportionment are greatly below expectation. The rules for choosing which projects to cut have been developed on an ad hoc basis throughout the process. The first test is readiness; in other words, a project that is not ready to obligate funds either

TABLE 3 PROJECT JUSTIFICATION WORKSHEET

1.	OPERATOR: BA	WORKSHEET FILE NAME: BA91-143.WK1	04-Jun-90
	LEAD AGENCY: BA	PAGE: 1	143 FORM

3. COST IN PROGRAM YEAR (INFLATED DOLLARS)

2. PROJECT NAME AND PROJECT DESCRIPTION		FISCAL YEAR	FEDERAL FUND CODE	FEDERAL FUNDS REQUESTED	STATE FUND CODE	STATE FUNDS REQUESTED	LOCAL MATCH CODE	LOCAL MATCH	TOTAL COST
NAME: Fruitvale AIP		91	9	$800,000			BT	$200,000	$1,000,000
Fruitvale AIP		92	9	$9,490,000	TPD	$1,186,000	BT	$1,186,000	$11,862,000
	0	93							$0
	0	94							$0
	0	95							$0
	0	96							$0
	0	97							$0
DESCRIPTION:		|							
First year funding for this		|							
project provides for design		|							
of bus transit interface.		TOTAL		$10,290,000		$1,186,000		$1,386,000	$12,862,000
NAME: Walnut Creek AIP		91	9	$800,000			BT	$200,000	$1,000,000
Walnut Creek AIP		92	9	$13,307,000	TPD	$1,663,000	BT	$1,664,000	$16,634,000
	0	93							$0
	0	94							$0
	0	95							$0
	0	96							$0
	0	97							$0
DESCRIPTION:		|							
First year funding for this		|							
project provides for design		|							
of bus transit & 1200 spaces.		TOTAL		$14,107,000		$1,663,000		$1,864,000	$17,634,000
NAME: Railroad Ave. Park/R		91	9	$552,720			OP	$138,180	$690,900
	0	92							$0
	0	93							$0
	0	94							$0
	0	95							$0
	0	96							$0
	0	97							$0
DESCRIPTION:		|							
This project is to acquire		|							
land and construct a 200		|							
space park/ride lot.		TOTAL		$552,720		$0		$138,180	$690,900
NAME: Brentwood Park/Ride		91	9	$281,400			OP	$70,350	$351,750
	0	92							$0
	0	93							$0
	0	94							$0
	0	95							$0
	0	96							$0
	0	97							$0
DESCRIPTION:		|							
This project is to construct		|							
a 100-space park/ride lot		|							
in the city of Brentwood		TOTAL		$281,400		$0		$70,350	$351,750

TABLE 4 IMPLEMENTATION SCHEDULE AND EXPENDITURE PLAN

Date: January 30, 1990

Project: Fruitvale Access Improvements
Operator: SAN FRANCISCO BAY AREA RAPID TRANSIT DISTRICT

Initial Clearances Required:

IMPLEMENTATION SCHEDULE:	FY 89/90 Q1 Q2 Q3 Q4	FY 90/91 Q1 Q2 Q3 Q4	FY 91/92 Q1 Q2 Q3 Q4	FY 92/93 Q1 Q2 Q3 Q4
EIR	===	=========		
Prepare RFP		===	===	
Bid/Award			O=======O	
Construction				===========

O: Clearances and Approvals
X000

EXPENDITURE PLAN (000$):	FY 90/91	FY 91/92	FY	FY
UMTA SEC. 9	800	9,490		
UMTA SEC. 3				
OTHER FED.				
STATE TP&D		1,186		
ARTICLE XIX				
RAIL BONDS				
PCL BONDS				
OTHER STATE				
LOCAL FUNDS SOURCE:				
BRIDGE TOLLS	200	1,186		
TOTAL FUNDS	1,000	11,862		

is scaled down to where it can commit or is bumped out to the next year. When shifted to a new year, however, the project may rank poorly or highly, depending on the array of scores in that year versus the fund constraint. For instance, the FY 1991 list, presented in Table 6, contains 6 projects having a score of 10. If the final apportionment were to fall in that block ($40 to $44 million), some of the 10s and all of the 8s and 9s would bump out to FY 1992. In that year, the 10s would probably be funded, but all of the FY 1990 8s and 9s would be bumped into the next year (see Table 7). Hence, the process may start with a rational multiyear array of staged projects and end up with an unwanted jumble.

It may be more reasonable in some cases, then, to simply scale back all projects proportionate to the funding cuts. That strategy may work well for easily divisible projects (such as vehicle purchases) but may not be feasible for facilities and equipment that are not easily divisible purchases.

CONCLUSIONS AND FUTURE PROSPECTS

The regional capital priority-setting process is similar to the talking dog, i.e., the significance lies not in what it says but merely that it talks at all. Given a history of conflict, a large

TABLE 5 PROJECTED ANNUAL EXPENDITURES

PAGE: 1
143A FORM

PROJECT NAME		ANNUAL ELEMENT FISCAL YEAR 91	PROJECTED FY 92	PROJECTED FY 93	PROJECTED FY 94	PROJECTED FY 95	PROJECTED FY 96	PROJECTED FY 97
Fruitvale AIP	F	800,000	9,490,000	0	0	0	0	0
	S	0	1,186,000	0	0	0	0	0
	L	200,000	1,186,000	0	0	0	0	0
	T	1,000,000	11,862,000	0	0	0	0	0
7-Year Project Total:								12,862,000
Walnut Creek AIP	F	800,000	13,307,000	0	0	0	0	0
	S	0	1,663,000	0	0	0	0	0
	L	200,000	1,664,000	0	0	0	0	0
	T	1,000,000	16,634,000	0	0	0	0	0
7-Year Project Total:								17,634,000
Railroad Ave. Park/R	F	552,720	0	0	0	0	0	0
	S	0	0	0	0	0	0	0
	L	138,180	0	0	0	0	0	0
	T	690,900	0	0	0	0	0	0
7-Year Project Total:								690,900
Brentwood Park/Ride	F	281,400	0	0	0	0	0	0
	S	0	0	0	0	0	0	0
	L	70,350	0	0	0	0	0	0
	T	351,750	0	0	0	0	0	0
7-Year Project Total:								351,750

1. OPERATOR: SAN FRANCISCO BAY AREA RAPID TRANSIT DISTRICT

2. PROJECT NAME: FRUITVALE ACCESS IMPROVEMENTS (FRUITVAL.PJW)

3. PROJECT DESCRIPTION: First-year funding for this project provides for the design of bus transit interface improvements and approximately 560 parking spaces (including site replacement spaces) in a multi-level structure on BART-owned land.

4. PROJECT CLASS: 7

5. SRTP PAGE REFERENCE: PP 20-22 CIP TIP PAGE REFERENCE:

6. PROPOSED FEDERAL FUNDING: $ 800,000 SOURCE: Section 9

7. PROPOSED LOCAL MATCH (20%): $ 200,000 SOURCE: Bridge Tolls

8. TOTAL PROJECT COST: $1,000,000

9. PRIOR UMTA FUNDING: None

10. ENVIRONMENTAL DOCUMENT TYPE AND STATUS:

NEPA STATUS: Environmental documentation per 23 CFR 771.117(d) et. seq.

CEQA STATUS: Determination of significant environmental effects per Sec. 15063 et. seq.

11. COMPLIANCE WITH PRIVATE SECTOR PARTICIPATION REQUIREMENTS (PLEASE COMPLETE FOR ANNUAL ELEMENT PROJECTS ONLY):

a. Was the private sector involved in the development on this project as set forth in your adopted policy?

__X__ No. _____ Yes: SRTP Page Reference __________

b. Were proposals received from the private sector to operate, construct, or otherwise provide all or part of the above named project?

* _____ No. __X__ Yes: SRTP Page Reference __________
(If yes, how were those proposals evaluated? Reference __________)

c. Are there impediments affecting your ability to contract for the above named project?

__X__ No. _____ Yes: SRTP Page Reference __________
(If yes, have you taken measures to address the impact of these impediments? Reference __________)

FIGURE 9 Project justification worksheet for projects submitted for the annual element of MTC's transit capital priorities. ***(continued on next page)***

d. Have you received any formal complaints from the private sector regarding this project?

__X__ No. _____ Yes: SRTP Page Reference __________
(If yes, how have the complaints been addressed? Reference __________)

* Construction of this project will be contracted out following BART's formal bid procedures.

12. ADDITIONAL PLANNING JUSTIFICATION:

Existing intermodal transfer areas are shared by bus and auto modes. In addition, a significant portion of the parking access takes place on the same access roads. Presently, four bus bays are provided on site.

The proposed project will provide a minimum of twelve bus bays and the separation of the bus and auto access improving general circulation, as well as street circulation in the vicinity of the station. In additional, kiss/ride and bus bays would be separated, improving flow for both modes.

A sawtooth design for bus bays will provide independent berthing for all buses. Covered wait and walk areas would be provided at the bus access points along with improved signage and transit information. Other improvements will include landscaping. BART will explore the feasibility of direct bus to train access, which may include automatic ticket machines, transfer machines, bill/coin changer, and new fare gates. These improvements would be added to this scope of work if feasible and justified.

AC Transit is in the process of implementing a modified grid system throughout the central core of its service area (Oakland, Berkeley, Alameda, Albany, Emeryville, and Piedmont). There are some locations where several bus routes naturally converge creating the need to accommodate several buses at once and facilitate ease of transfer between buses. In the central core, Fruitvale Station must be improved before route restructuring can take place. It simply cannot accommodate the level of bus and transfer activity envisioned. The planned increase is from the current maximum of four simultaneous loadings up to a future twelve such loadings.

Significant restructuring of the existing parking lot is required to support improved multimodal access.

FIGURE 9 ***(continued from previous page)***

TABLE 6 FY 1991–1997 FIVE-YEAR TRANSIT CAPITAL PRIORITIES FOR YEAR 1

Final CPList91
01-May-90

OPERATOR	CODE & PROJECT NAME (1)	SCORE (2)	FEDERAL SHARE (3)	CUMULATIVE FEDERAL SHARE (4)
FY 91	SF/O Section 9			
JPB02	SF Terminal Ext.	NRS	$1,312,500	$1,312,500
AC01	Repl Buses -33 SML	16	5,010,768	6,323,268
GG01	Repl Buses -23	16	4,473,063	10,796,331
AC01	Repl Buses -72 SML *	16	9,238,770	20,035,102
GG01	Repl Buses -16 *	16	3,111,692	23,146,794
AC05	Oil Water Separators	14	147,000	23,293,794
CT21	Accessibility (SF)	14	2,372,932	25,666,726
GG05	Fuel Storg San Raf ~	14	1,439,086	27,105,812
SM02	Repl Vans - 4 @,&	14	281,280	27,387,092
CT22	Ticket Vend Equip @	13	1,166,497	28,553,589
BA01	Fruitvale AIP	11	800,000	29,353,589
BA02	Walnut Creek AIP	11	800,000	30,153,589
MU07	Fixed Facility Rehab	11	6,674,080	36,827,669
MU15	Trolley Ovhd REC-#14	11	3,035,096	39,862,765
AC02	Svc Vehicle Repl-12	10	165,440	40,028,205
AC4A	Bus Fueling Nozzle	10	672,000	40,700,205
MU08	Misc Maint & Repair	10	1,144,500	41,844,705
MU09	Non-Revenue Vehicles	10	729,304	42,574,009
MU22	Replace 24th & Utah	10	449,496	43,023,504
SM15	Exp Buses-(6 w/over)	10	674,458	43,697,962
AC03	Replace Lifts	9	1,751,160	45,449,122
MU10	DP & Office Equipmen	9	875,164	46,324,286
MU14	Rehab 10 PCC Stcars	9	2,632,632	48,956,918
CC01	Maint Shop Equip.	8	254,770	49,211,688

"AIP" is an abbreviation for the BART station access improvement projects, and includes construction of bus loading bays near station entrances and additional patron parking spaces around station.

* Project moved from FY 1992 to meet expected apportionment.
Lower apportionment bumps these projects first, proportionately.

~ Pending verification of emergency status.

@ Projects may not displace any other project originally programmed for FY 1991.

& SamTrans' unit cost for replacement vans is not an adopted standard for future programming. Standard unit costs will be developed by MTC staff and the TOCC.

TABLE 7 FY 1991–1997 FIVE-YEAR TRANSIT CAPITAL PRIORITIES FOR YEAR 2

Final CPList91
01-May-90

OPERATOR	CODE & PROJECT NAME (1)	SCORE (2)	FEDERAL SHARE (3)	CUMULATIVE FEDERAL SHARE (4)
FY 92	SF/O Section 9			
GG02	Replacement Ferry	15	3,571,505	3,571,505
MU05	Trolley Coach SPEC	15	400,000	3,971,505
SM01	Repl Buses - 62	15	10,369,723	14,341,228
CC02	Rehab 14 Buses *	14	368,480	14,709,708
SM02	Repl Vans - 10 &	14	145,477	14,855,185
MU35	Cable Car Veh Rehab	13	490,000	15,345,185
AC06	Transit Centers Devl	11	2,182,400	17,527,585
BA01	Fruitvale AIP	11	3,200,000	20,727,585
BA02	Walnut Creek AIP	11	2,600,000	23,327,585
BA06	Concord AIP	11	800,000	24,127,585
MU07	Fixed Facility Rehab	11	4,304,480	28,432,065
MU15	Trolley Ovhd Rec-#14	11	3,186,852	31,618,917
MU29	14-Missn to DC BART	11	1,798,574	33,417,491
CC13	Paratransit Fac.	11	1,564,000	34,981,491

"AIP" is an abbreviation for the BART station access improvement projects, and includes construction of bus loading bays near station entrances and additional patron parking spaces around station.

* Section 9 portion will be increased to $726,880 if TIP amendment to re-obligate prior year bus purchase grants is unsuccessful. (also includes deob of:

& Standard paratransit van unit costs will be reviewed by MTC staff and TOCC Includes overmatch for standard paratransit vans, minus FY 1991 swap amount.

number of players, and shrinking resources, the deck would seem to be stacked against the success of a process predicated on consensus building and budget cutting. Paradoxically, those negatives seem to have contributed to its success.

The history of conflict established the need for a new approach to developing a regional program that could be supported by, and could benefit, all. The large number of roughly equal players caused independent coalition building to be time consuming and frustrating. With no long-term basis for cooperation, any coalition was unlikely to last beyond the immediate need of a specific negotiation. Finally, the immediacy and severity of the Gramm-Rudman cuts necessitated a streamlined procedure for communicating quickly on all channels; bilateral negotiations among operators could not have coped efficiently with such shocks.

With an annual review requirement, MTC will always seek to correct deficiencies in the process. It is likely, for instance, that an approach similar to Philadelphia's will be developed in the future—somewhat more quantitative and more complex—in response to a desire for more rigor. In particular, a more explicit connection will be sought between the long-range estimates of capital replacement needs and the annual 5-year program update. The Transit Finance Plan plotted the annual capital requirement according to a strict asset life replacement schedule and found that there were extraordinary year-to-year swings (see Figure 10). A strategy will have to be developed as shown to smooth out those needs and translate them into annual programming.

As long as significant federal and state funding exists for public transportation, MTC's capital priority-setting process will be needed to develop a unified regional program. Without MTC, the operators would have had to invent a similar process on their own. As the future of public transportation funding becomes increasingly complex and varied, program coordination at the regional level will become even more essential. This early effort may some day be seen as a charmingly simple-minded attempt to impose an artificial order on a chaotic environment.

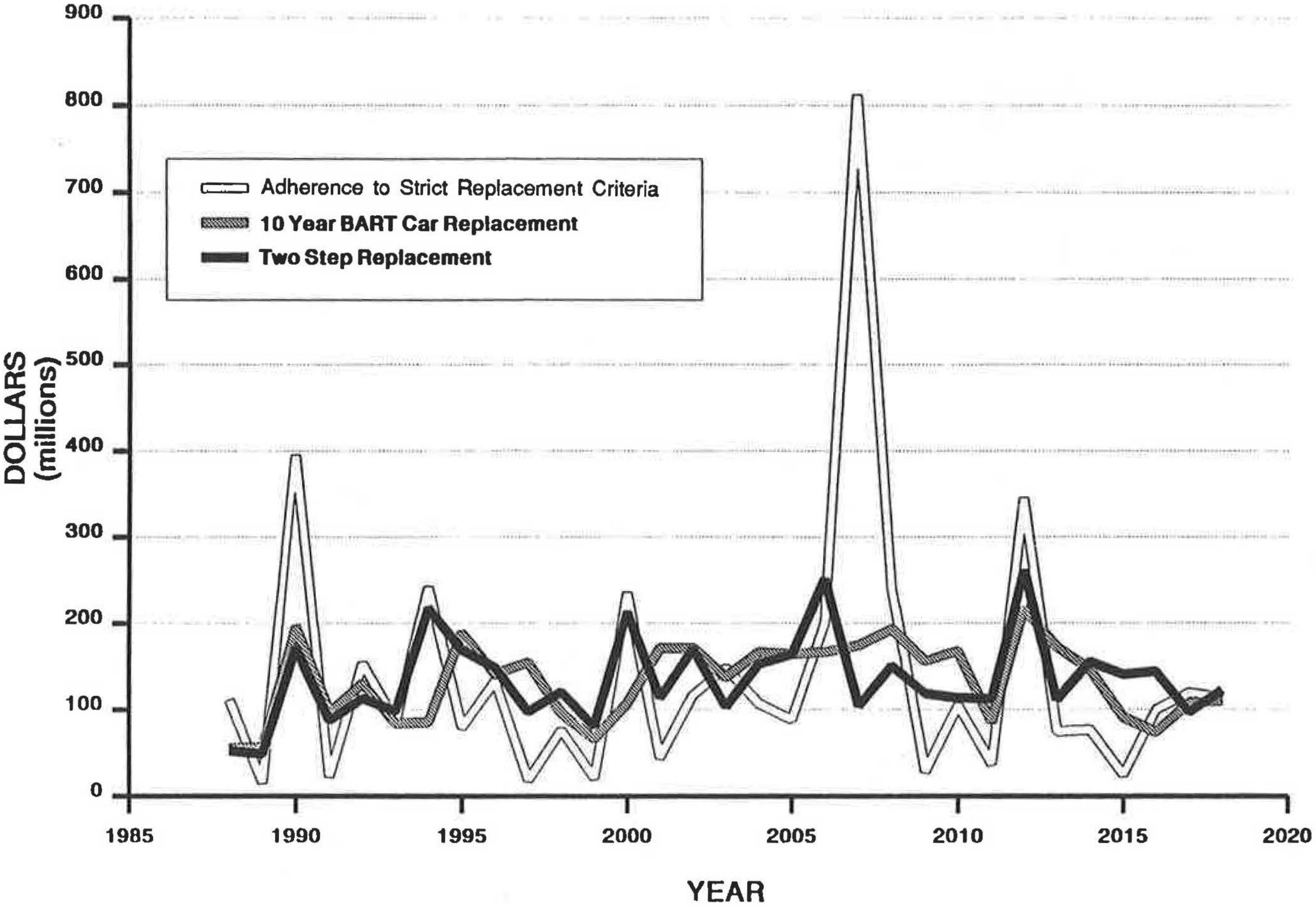


FIGURE 10 **Annual capital replacement needs for alternative funding concepts.**

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Capital Project Priority Setting at the Southeastern Pennsylvania Transportation Authority

CAROL H. LAVORITANO, RICHARD G. BURNFIELD, AND JEFFREY H. GLISSON

Beginning with its FY 1989 capital program, the Southeastern Pennsylvania Transportation Authority (SEPTA) introduced a methodology for setting priorities for capital projects. The priority-setting methodology evaluates 12 financial and nonfinancial factors, which are each given a weight. The choice of factors and weights was based on the goals and criteria SEPTA believed were important for setting capital project priorities in the Philadelphia metropolitan area. Projects considered to be appropriate candidates for capital funding are evaluated using the priority-setting methodology. A total numerical score for each project is calculated by adding the results from the 12 factors, which creates a numerical ranking of the projects in descending order from 1 to *n*. However, capital projects mandated by regulation or legislation receive first priority for funding, regardless of their priority-setting score.

According to state legislation, the Southeastern Pennsylvania Transportation Authority (SEPTA) must prepare and adopt a capital budget and a 6-year capital program each year. Together, the capital budget and program provide an outline of SEPTA's capital needs and an investment plan for the future.

Since FY 1980, SEPTA has expended over $1 billion on capital improvements from federal, state, and local funds. The investment of these funds contributed to a significant improvement in the quality, reliability, and attractiveness of SEPTA services. The capital program's previous impact and the critical role it will have on SEPTA's future have caused considerable attention to be focused on the selection and programming of projects in the capital budget and program. This attention has been reinforced as the gap widens between SEPTA's future capital needs and available capital funds and as the search for alternative sources of capital funding intensifies. As a result, the SEPTA Board of Directors charged the staff with developing a formalized methodology for setting priorities among proposed capital projects.

BACKGROUND

After reviewing the literature on capital project priority setting, SEPTA hired the consulting firm of Gannett Fleming Transportation Engineers, Inc., to identify, research, and review the methodologies used by other multimodal transit authorities. The results of this research indicated that the existing capital project priority-setting methodologies can be grouped into three general categories:

1. Evaluating capital projects intended for new markets or for expanding service,
2. Assessing and documenting capital needs, and
3. Evaluating and setting priorities for individual capital projects.

SEPTA concluded that the methodologies used in the first category were not appropriate for rehabilitation and replacement projects, which are the kind usually evaluated by SEPTA. With respect to the second category, general inventories and assessments of SEPTA's capital assets have been undertaken in the past by various in-house and consultant efforts. Although a detailed and specific analysis of SEPTA's assets by category, age, and expected service life would provide useful information, this kind of methodology would not fully address all SEPTA capital projects or incorporate factors reflecting SEPTA's existing capital funding situation.

The methodologies in the third category were considered to be the most appropriate resource in developing a priority-setting process for SEPTA. The following methodologies were reviewed in some detail:

- Metropolitan Transportation Authority of New York, Capital Value Matrix;
- New Jersey Transit, Rail Operations Capital Project Planning;
- New Jersey Transit, Process for Evaluating Capital Projects;
- Washington Metropolitan Area Transit Authority, A Methodology for Projecting Rail Transit Rehabilitation and Replacement Capital Financing Needs; and
- Strategic Planning for Capital Investment Programming: A Case Study of the Regional Transportation Authority in Chicago.

Generally, methodologies of this kind include an initial evaluation of the project to determine whether it can be categorized as essential, normal replacement, or discretionary. The next step is to assess the financial and nonfinancial benefits of the projects. Factors used to assess the nonfinancial benefits include safety, reliability, security, passenger envi-

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ronment, and regional development. Each factor is assigned a score and weight that reflect local concerns and conditions.

MAJOR ISSUES

In developing a priority-setting methodology, several issues were initially addressed. SEPTA assumed the existing system would be retained with no major expansion or reduction in service. This assumption resulted in a discussion of two major issues:

- Should priorities for improvements be determined by line (as in a systems approach) or by project?
- Should projects on select rail lines receive more points than projects on other lines?

A systems approach to rehabilitating all infrastructure components on a rail line is considered the best method for implementing capital improvements. However, with SEPTA's significant capital needs and limited funding, the systems approach was not considered to be a viable option. For this reason, SEPTA staff determined that priorities should be set on a project-by-project basis with projects on select rail lines receiving more points than projects on other lines.

To identify these select rail lines, SEPTA developed a methodology to evaluate and assess the benefits from operating or continuing to operate service on rail transit and regional rail lines. The lines were scored on nine factors, which evaluated them in the following areas: operating cost efficiencies, ridership, future capital investment, role in the region's economy and transportation system, and alternative service. A weight was assigned to each factor, and the scores were totaled to determine a final numerical ranking for each line. These totals were then used to rank the routes as high, medium, or low on one of the criteria used in setting priorities among individual capital projects (discussed in the next section). The bus system was not subjected to the line rating evaluation because of the multitude of routes, the relatively low capital-intensive nature of the system, and the flexibility of route assignments among the various bus garages.

The methodology used for ranking the rail transit and regional rail routes is presented in Table 1. The results of this evaluation are presented in Table 2.

DEVELOPMENT OF PRIORITY-SETTING METHODOLOGY

After the decisions were reached on these initial issues, the SEPTA staff developed a methodology for setting capital project priorities. The methodology includes 12 financial and nonfinancial factors, of which each factor is given a weight. The choice of factors and weights was based on SEPTA's goals, the criteria used by other transit authorities in their methodologies, and the criteria SEPTA believed were important for setting capital project priorities in the region. The factors included in the priority-setting methodology require an evaluation of a project on 12 different attributes, ranging from safety and service quality to location of project and passenger comfort. This broad-based approach, in terms of the number of factors included, ensures that all different aspects of a project are considered.

The 12 factors are presented in Table 3.

USE OF METHODOLOGY

SEPTA used the priority-setting methodology to evaluate projects considered for inclusion in its FY 1989 and 1990 capital budgets. A total numerical score was calculated for each project by adding the results from the 12 factors. The result was a numerical ranking from 1 to *n* of the projects in descending order of priority. Capital projects mandated by regulation or legislation received first priority for funding, regardless of their priority-setting score.

After the initial use of the methodology in FY 1989, the weighting of several factors was changed to reflect changes in SEPTA's direction. As stated in its action plan for the 1990s, SEPTA has renewed its commitment to service improvements, passenger amenities, and environmental concerns. As a result, the weighting for five factors was revised. First, the weight of the passenger comfort and convenience factor was increased from 3 to 7 because SEPTA has made an increased commitment to improve services for its passengers. Second, the weighting for the traffic congestion relief factor was increased to reflect the positive impact of transit use on the environment. Automobile use significantly affects air pollution levels and the overall quality of life in metropolitan areas, and much attention has been focused on strategies to improve air quality. Therefore, the revised weighting for this factor reflects the positive impact increased transit use will have by reducing automobile travel and highway congestion. Third, the weight for the critical nature of project factor was decreased from 7 to 6 because it was felt that the highest weighted factor—safety—is also a measure of the project's urgency. Fourth, the weight for the location of project factor was reduced from 7 to 6 because it was agreed that the existing system should be retained. Finally, the weighting for the previous commitment to project factor was decreased because SEPTA recently completed several capital projects and the number of projects to which it previously had been committed was a relatively small percentage of the program. Therefore, it was felt that the previous weighting of this factor was overstated.

These revisions permit the advancement of projects that reflect SEPTA's policy changes. The ability to incorporate the revisions demonstrates that the priority-setting methodology is a dynamic process designed to accommodate an ever-changing environment.

ADVANTAGES OF METHODOLOGY

As previously stated, the priority-setting methodology was used by SEPTA to develop its FY 1989 and 1990 capital budget and program. The methodology is now recognized as the official process for evaluating and ranking transit capital projects in the Philadelphia metropolitan area. The existence of a formalized process provides an effective decision-making tool for SEPTA senior management and policy makers. The process has been well received both by funding agencies and elected officials.

TABLE 1 FACTORS USED TO RANK RAIL TRANSIT AND REGIONAL RAIL LINES

Factor	Description	Scale	Weight
1. Operating ratio	Allocated operating costs divided by revenue.	0 = 3.000 and over 1 = 2.500 to 2.999 2 = 2.000 to 2.499 3 = 1.500 to 1.999 4 = 1.000 to 1.499	10
2. Operating cost per passenger	Allocated operating costs divided by annual unlinked passengers.	0 = 3.00 and over 1 = 2.50 to 2.99 2 = 2.00 to 2.49 3 = 1.50 to 1.99 4 = 1.00 to 1.49	10
3. Investment per rider	Total capital investment required to rehabilitate the line divided by average weekday ridership on the line.	0 = Over $20,000 per rider 1 = $15,000 to $20,000 per rider 2 = $10,000 to $14,999 per rider 3 = $5,000 to $9,999 per rider 4 = $1 to $4,999 per rider	10
4. Investment per passenger mile	Total capital investment required to rehabilitate the line divided by average weekday passenger-miles.	0 = Over $5,000 per passenger-mile 1 = $3,750 to $4,999 per passenger-mile 2 = $2,500 to $3,749 per passenger-mile 3 = $1,250 to $2,499 per passenger-mile 4 = $1 to $1,249 per passenger-mile	10
5. Current ridership	Current ridership figures for the line.	1 = 1 to 4,999 riders 2 = 5,000 to 9,999 riders 3 = 10,000 to 20,000 riders 4 = Over 20,000 riders	8
6. Potential for growth retaining current ridership	Impact of continued service on the potential for growth in ridership or retaining current levels of ridership on the basis of investment in capital improvements and the market served by the line.	0 = No impact 1 = Minimal growth (0.1% to 3.4%)[a] and minimal impact on current ridership 2 = Moderate growth (3.5% to 6.9%) and moderate impact on current ridership 3 = Significant growth (7.0% to 10.4% and significant impact on current ridership 4 = Critical growth (over 10.5%) and critical impact on current ridership	7
7. Regional development	Impact of continued service in terms of encouraging, enhancing, and improving the potential for economic development or ensuring the continuation of a strong economy. Consideration is given to surrounding land uses and plans or potential for economic development.	0 = No impact 1 = Minimal impact 2 = Moderate impact 3 = Significant impact 4 = Critical impact	7
8. Alternative mode of service	Availability of a technically feasible alternative transit mode(s) to replace the line if service is abandoned.	−2 = Viable and feasible alternative mode of service is available. −1 = Viable and feasible alternative mode of service may be available. 0 = Not clear whether viable and feasible alternative mode of service is available. 1 = No viable and feasible alternative mode of service is likely to be available. 2 = No viable and feasible alternative mode of service is available.	6
9. Transportation	Evaluation of the role and impact of the line on the transportation network in the region. Factors considered are the relationship between highways and rail lines, traffic flow, and the ability to travel through the region.	0 = No impact 1 = Minimal role and impact 2 = Moderate role and impact 3 = Significant role and impact 4 = Critical role and impact	6

[a] Percentages are intended to provide guidance in evaluating the impact on ridership.

TABLE 2 ROUTE INDEX FOR CAPITAL IMPROVEMENTS

RAIL ROUTE	OPER RATIO	OPER PASS	INV/ RIDER	INV/ PASSM	CURR RIDER	RIDER GROW	REG DEV	ALTER MODE	TRANSP	TOTAL
(Weight of Factor)	10	10	10	10	8	7	7	6	6	
RAIL TRANSIT										
BSS	30	40	40	40	32	28	28	12	24	274
MFSE	30	40	40	40	32	28	28	12	24	274
Subway-Surface	20	30	40	40	32	21	21	12	18	234
Route 56	40	40	30	20	24	21	14	-6	12	195
Media-Sharon Hill	30	30	40	40	16	7	7	0	12	182
Route 23N	30	40	30	20	24	21	14	-12	12	179
Route 15	30	40	30	10	24	21	14	-6	12	175
NHSL	0	0	30	40	16	28	21	12	18	165
REGIONAL RAIL										
Lansdale/ Doylestown	10	0	30	40	24	21	28	12	24	189
Media	0	0	30	40	16	14	14	12	18	144
West Trenton	0	0	30	40	16	14	21	6	12	139
Warminster	0	0	30	40	16	14	14	6	6	126
Chestnut Hill East	0	0	30	40	8	14	14	-6	12	112
Chestnut Hill West	0	0	30	40	8	14	14	-6	12	112
Fox Chase	0	0	30	40	8	14	7	6	6	111
Norristown	0	0	0	30	8	14	14	6	12	84
Ivy Ridge	0	0	10	30	8	7	0	-12	6	49

NOTE: The Marcus Hook, Paoli and Trenton lines operate on Amtrak-owned facilities. The Airport Line recently opened and does not need capital investment at this time.

The process was successful in identifying the highest and lowest ranked projects. However, many projects were closely ranked in the middle of the scale. Because capital funding resources are currently limited, the process worked well from the perspective that only the highest ranked projects were advanced. However, as additional funding becomes available, the need to distinguish among closely ranked projects will have to be addressed.

LIMITATIONS OF METHODOLOGY

Some limitations were identified by using the process for the FY 1989 and 1990 capital budgets. One major area requiring improvement is the subjectiveness of some factors. In particular, it is difficult to measure the impact of a project on such factors as economic development, passenger comfort, and traffic congestion relief. It is SEPTA's goal to work toward a more quantifiable and supportable process.

Differences in the scale and scope of the projects proved to be a significant problem. Projects evaluated as part of this effort range from specific, localized projects to large, systems-oriented projects. In addition to the inherent problems associated with comparing projects of different scales, the systems-oriented projects tend to rank higher in terms of their potential to have a greater benefit on many of the factors evaluated. One avenue under consideration is a method for breaking down large-scale projects into smaller, individual projects.

The lack of uniform base data is another problem because the SEPTA capital program includes more than 200 projects in various stages of development and definition. Projects that are close to implementation tend to be better defined and documented when compared with projects in the later years

TABLE 3 FACTORS USED TO SET CAPITAL PROJECT PRIORITIES

Factor	Description	Scale	Weight
1. Safety	Potential improvement in safety and security for passengers and employees. This includes safety in operations and in accessibility to the system.	0 = No impact 1 = Minimal impact 2 = Moderate impact 3 = Significant impact 4 = Critical impact	10
2. Service quality	Estimated degree of change and improvement in reliability (on-time performance), frequency (headway), and travel time. Current conditions in service quality are compared with the anticipated level of service quality after the improvements.	0 = No change 1 = Minimal change 2 = Moderate change 3 = Significant change 4 = Critical change	9
3. Current ridership	Current ridership for the line, route segment, or station affected by the project.	0 = New project 1 = 1,000 to 4,999 riders 2 = 5,000 to 9,999 riders 3 = 10,000 to 20,000 riders 4 = Over 20,000 riders	8
4. Investment per rider	Current estimated cost for the capital project divided by current average weekday ridership. Ridership is by line or lines, station, subsection of a line, and so on, depending on the project.	0 = Over $10,000 per rider 1 = $7,500 to $9,999 per rider 2 = $5,000 to $7,499 per rider 3 = $2,500 to $4,999 per rider 4 = $1 to $2,499 per rider	8
5. Ridership	Estimated impact in terms of encouraging or attracting new riders to the line or to the station being improved. It is assumed that ridership growth will result in increased revenue.	0 = No impact 1 = Minimal impact (0.1% to 3.49% increase)[a] 2 = Moderate impact (3.5% to 6.9% increase) 3 = Significant impact (7% to 10.5% increase) 4 = Critical impact (over 10.5% increase)	7
6. Operating cost impact	Estimated beneficial or negative impact on operating costs.	0 = No impact; changes in operating costs and revenue are offset +1/−1 = Minimal impact (0.1% to 2.49% change)[b] +2/−2 = Moderate impact (2.5% to 4.9% change) +3/−3 = Significant impact (5.0% to 7.5% change) +4/−4 = Critical impact (over 7.5% change)	7
7. Passenger comfort and convenience	Estimated positive impact on passenger comfort, convenience, and amenities.	0 = No impact 1 = Minimal impact 2 = Moderate impact 3 = Significant impact 4 = Critical impact	7
8. Critical nature of project	Evaluation of the condition of the facility to be rehabilitated or replaced or of the vehicle to be overhauled or replaced and the need for the project in order to continue operating service. An assessment of the condition of SEPTA's assets provides an input to the evaluation of a project for this factor.	0 = No critical need/ completion of project eventually needed for continued operation (over 10 years) 1 = Completion of project needed for continued operation (9 to 10 years) 2 = Completion of project important for continued operation (6 to 8 years) 3 = Completion of project a priority for continued operation (3 to 5 years) 4 = Completion of project critical for continued operation (immediate to 2 years)	6

TABLE 3 *(continued on next page)*

TABLE 3 (*continued*)

Factor	Description	Scale	Weight
9. Location of project	A line-by-line analysis of the rail transit and regional rail lines is conducted to determine which lines generate the greatest benefits from an operating, transportation, and economic perspective. The result of this analysis is a ranking of the lines. Because the system's approach is not feasible under a limited funding scenario and the assumption is that service will continue on all lines, the ranking of the lines is used to evaluate an individual project on the basis of its location and overall impact on the system.	0 = System expansion project 1 = Project located on line ranked "low" 2 = Project located on line ranked "medium" 3 = Project located on line ranked "high" 4 = Systemwide project, not line specific	6
10. Traffic congestion relief	Evaluation of potential to reduce traffic congestion by attracting additional riders to the line or system. A reduction in auto traffic would have a beneficial impact on air pollution and energy use.	0 = No impact 1 = Minimal impact 2 = Moderate impact 3 = Significant impact 4 = Critical impact	6
11. Economic development	Estimated impact in terms of encouraging, enhancing, and improving the potential for economic development or ensuring the continuation of a strong economy on the basis of adjacent land uses and future development plans.	0 = No impact 1 = Minimal impact 2 = Moderate impact 3 = Significant impact 4 = Critical impact	5
12. Previous commitment to project	Evaluation of degree of previous SEPTA commitment to the project (whether engineering is underway or completed) or whether implementation of the project will ensure effective utilization of a previous project.	0 = New start/initiate major rehabilitation 1 = Minimal level of previous commitment to project 2 = Moderate level of previous commitment (i.e., engineering in progress) 3 = Significant level of previous commitment (i.e., engineering is complete) 4 = Additional phase of previously funded project; project will ensure effective utilization of previous project or phase	3

[a] Percentages are intended to provide guidance in evaluating the impact on ridership.

[b] Percentages are intended to provide guidance in evaluating the impact on operating costs. The positive numbers indicate decreases in operating costs, whereas the negative numbers indicate increases in these costs.

of the capital program. This lack of uniform base data may serve as a bias against projects with incomplete and poorly documented data.

One factor not addressed by the process is the interrelationship among projects. For example, the process does not indicate whether one project must be underway or completed before a second project can be initiated. It would be helpful to evaluate the desirability or requirement of simultaneously advancing two or more projects.

Closely related to this issue is the concern of whether adequate project management capabilities exist to advance the project if funding becomes available. The availability of project management resources is important for two reasons. First, the value of funds decreases over time because of inflation; as a result, a project may have to be redesigned or scaled back to fit within available resources or additional funding may need to be requested. Second, to support transit's position that additional funds are required, SEPTA must be prepared to expend funds quickly. Delays in program implementation may result in a loss of credibility; in other words, it may seem that funds were not actually required or that the infrastructure was not as badly deteriorated as stated.

In summary, SEPTA has found that a professional and documentable approach to capital project selection is critical. As competition for public- and private-sector funds increases, transit must be prepared to document the need to rebuild the existing infrastructure and serve new and emerging markets.

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Vehicle Replacement Strategies: Opportunities for Efficiencies

DOUGLAS W. CARTER, RICHARD DRAKE, AND JIM SIMS

The economic outlook for transit indicates that the current scarcity both of operating and capital dollars will continue, and perhaps worsen. For example, many transit funding sources are growing at rates less than the inflation rate. Improving vehicle replacement strategies is one way to realize capital and operating cost savings. Faced with a planned vehicle replacement shortfall of $220 million over 10 years, the Los Angeles County Transportation Commission in conjunction with 13 Los Angeles County transit operators conducted a study to develop cost-effective vehicle replacement guidelines. The study efforts, which built on substantive prior nationwide capital replacement research, produced a simple yet effective means for evaluating cost impacts of alternative vehicle replacement schedules. The vehicle replacement methodology, which was developed comprehensively, incorporated vehicle procurement strategy, routine maintenance practices, and vehicle subsystem rebuild planning in the replacement decision. The vehicle replacement methodology and its associated data reasonably reflected the experience of the Los Angeles County operators. Cost savings could be identified in excess of $117 million in FY 1989 dollars over the next 10 years.

An FY 1988 nationwide transit vehicle replacement survey of 166 responding transit operators indicated that bus replacement decisions were generally based on availability of federal and local matching funds. Fully 96 percent of the respondents indicated that the federal guidelines of 12 years or 500,000 mi controlled their vehicle replacement decisions. Lack of local match monies was cited as the main reason for longer replacement cycles, when it occurred. Less than 12 percent of total respondents indicated that operating costs, major failures, or recent repairs entered into replacement decisions. Until FY 1989, the 13 Los Angeles County transit operators were not among this small percentage. These transit operators have identified more than $117 million in FY 1989 dollars in total cost savings over 10 years as a result of incorporating maintenance cost, capital expense, and subsystem rebuild and failure information into their vehicle replacement decision-making process.

The economic outlook for transit indicates that the current scarcity both of operating and capital dollars will continue, and perhaps worsen. For example, the funding ability of many transit funding sources is growing at a rate less than the inflation rate. Such financial constraints necessitate efficiencies in vehicle replacement strategies as a means for minimizing capital and operating expenditures of transit operators. Transit fleet managers control capital and operating costs through vehicle replacement, rehabilitation, and deployment decisions. It is essential that they have sound cost information and analytic techniques to support fleet replacement decisions.

LOS ANGELES COUNTY—A CASE STUDY

In July 1988, the Los Angeles County Transportation Commission (LACTC) identified a $220 million shortfall in funding needed to meet the capital replacement requirements of 13 Los Angeles County bus operators between FY 1990 and FY 2000. The estimated shortfall was based on current funding levels of $578 million and operator vehicle replacement practices and plans of $798 million. The estimated cost did not provide service expansion to meet the projected FY 2000 population increase of more than 2 million people in the County, nor did the estimate include capital expenditures needed to meet air quality mandates.

In response to the critical shortfall, LACTC and the 13 transit operators began to develop vehicle replacement guidelines that would more efficiently use available transit operating and capital financial resources.

A Coach Replacement Methodology

Given the presence of real operating and capital financial constraints in the transit industry, particularly in Los Angeles, vehicle replacement guidelines should promote cost-effective decision making. Three key factors should be considered in determining from a low-cost perspective the retirement age of transit coaches:

- Capital costs, which are amortized across the useful life of a vehicle, decrease as vehicle age increases. Capital costs include the initial purchase price, major rebuild or remanufacture costs, minus any residual or salvage value at retirement.
- Basic maintenance costs, which reflect the higher costs of operation and repair associated with older vehicles, increase with vehicle age and accumulated mileage.
- Major subsystem rebuild costs can increase or decrease with age. Major rebuilds generally occur at fixed mileage intervals and provide additional years of useful vehicle life. The four subsystems in this category are engine, transmission, body, and frame, which have differing mileage intervals and costs. Any vehicle retirement schedule will reduce the benefits from one or more subsystem rebuilds. Replacement should be scheduled to minimize the overall rebuild cost across subsystems.

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In the nationwide survey mentioned previously, costs in these three categories were significantly affected by vehicle replacement schedules, although they were not typically evaluated in the replacement decision. The transit coach replacement methodology recognizes the unique response to increase in vehicle age of each of these cost categories.

The vehicle replacement methodology shown in Figure 1 assumes that all transit dollars are equal, regardless of source or restrictions placed on that source. Combined annual equivalent cost (AEC) is used for comparing the total cost of different replacement cycles. This comparison determines the schedule of incurred cost and spreads the costs equally across the years of useful life. To identify the low-cost alternative, AEC values for different useful lives can also be compared.

Cost implications of each factor were defined using individual transit operator data alone, but available data were insufficient in some areas for each of the operators involved. Some related nationwide studies include the National Cooperative Transit Research and Development Program Report 10 (*1*) and studies for other public and private large-fleet managers. These prior efforts resulted in an extensive data base of vehicle operating and maintenance costs for 170 transit coach fleets containing more than 10,000 buses and 18,000 cars, trucks, and vans over the life of each vehicle or fleet.

This nationwide data base provided specific cost relationships such as slope of operating cost increase with age and mileage; cost versus miles between vehicle subsystem rebuilds; and salvage value of vehicles related to miles, years, and purchase price, to supplement available local information. Los Angeles County transit operators carefully examined their vehicle fleet deployment practices in light of the nationwide cost relationships, and critically reviewed the results. In all cases, the results reasonably reflected the experience and understanding of the transit operators, so they agreed to use this supplementary information in developing vehicle replacement guidelines locally.

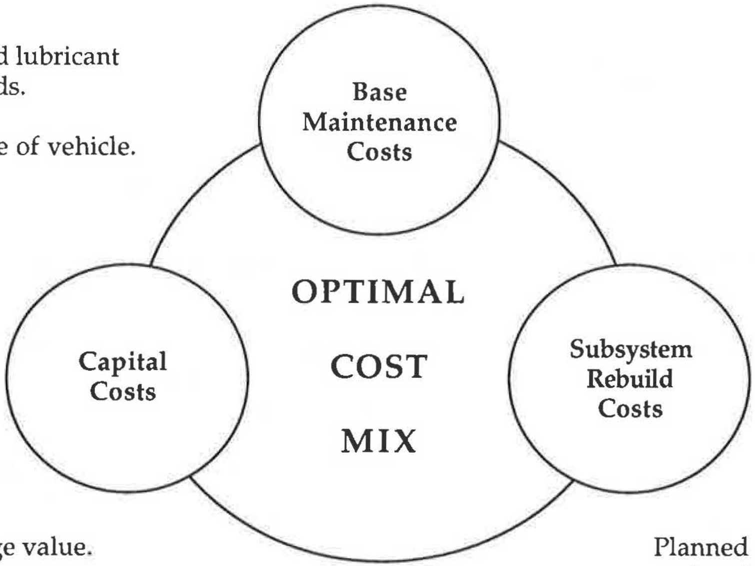
Vehicle Capital Cost

The capital procurement cost of a transit coach is a key cost consideration in a vehicle replacement decision. Because capital dollars purchase the use of a vehicle over a period of years, the purchase costs should be depreciated over the useful life of the vehicle. For a transit bus purchased with federal funds, the minimum depreciation schedule is 12 years or 500,000 mi. It is common practice to fully depreciate vehicles using the minimum federal guidelines even when vehicles are kept in service longer. Although this approach may be used for accounting purposes, the replacement analysis should depreciate vehicles over their full useful life. Other vehicles purchased using federal funds (e.g., vans, trucks, and automobiles) have a minimum depreciation schedule of 4 years or 100,000 mi.

A typical cost curve depicting average annual capital cost over a span of useful life options is shown in Figure 2. When vehicles have a significant salvage value, future sales revenue should also be spread over the vehicle's useful life to reduce overall costs. Salvage value information on transit buses less than 12 years old is not available. The transit bus market is highly specialized and resale markets for retired vehicles are often soft. The sales price of 6,500 buses retired and sold fell

Excludes fuel and lubricant costs, and rebuilds.

Escalate with age of vehicle.



Reduce by salvage value.

Amortized across the life of vehicle at a rate equal to long term T-Bill.

Costs are distributed over life of vehicle in equal annual amounts.

Planned major operating and maintenance investments.

Multi-year mileage intervals.

Provide extended life and performance.

FIGURE 1 Factors included in the Transit Vehicle Replacement Guidelines developed for Los Angeles County transit operators.

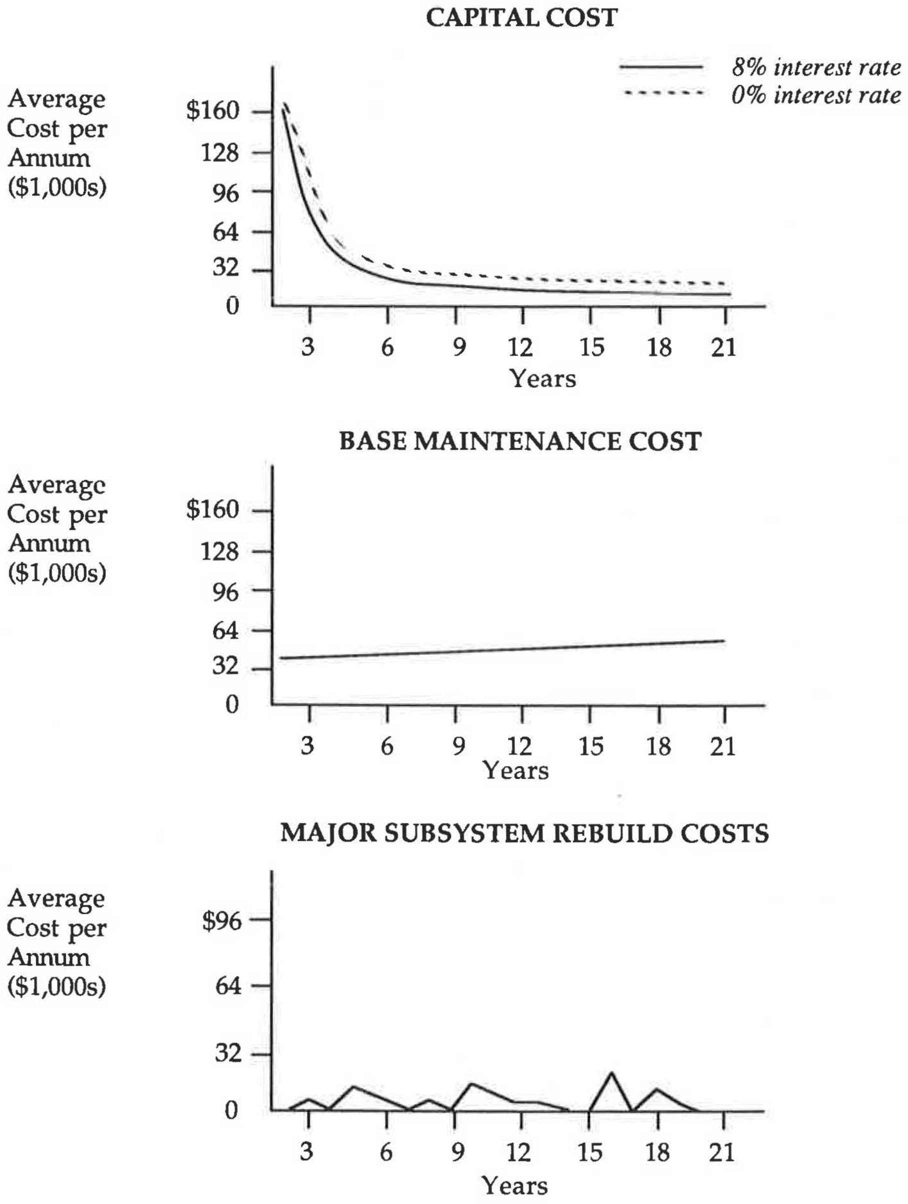


FIGURE 2 Review of ways in which transit coach costs change over time, in constant-dollar terms.

between $200 and $2,800 per coach. Although the salvage value is a revenue to be received in a future year, the vehicle replacement methodology examines all costs in current-year terms. When the salvage value is converted into present-day dollars, it is further diminished. For example, a salvage value of $1,000 in Year 12 is worth only $397 in present-day dollars. This amount, which compares to an initial purchase price of about $165,000 per coach, has little or no effect on the replacement strategy.

Although transit bus resale or salvage values appear to have little effect on overall investment cost, van, truck, and automobile resale values have a significant effect on their replacement strategies. Unlike the bus market, for these vehicles there is a strong second-hand support vehicle market with many potential buyers for most vehicles. On the basis of the resale of more than 8,500 support vehicles and examination of the automobile industry's blue book, a table of resale values was developed for use by the Los Angeles County transit operators in making replacement decisions, as presented in Table 1. The table assumes vehicles accumulate about 12,500 mi/year, but it can be adjusted to reflect other mileage rates. Given their large potential resale value, many support vehicles yield a smaller total cost when they are retired well before the 100,000-mi range.

Basic Maintenance Costs (BMCs)

The nationwide research confirmed the widely held belief that BMCs for a vehicle increase with both age and accumulated mileage. Research published by the National Cooperative Transit Research and Development Board in 1988 addressed this issue explicitly. An analysis of the operating costs for 160 operating bus fleets indicated that BMCs increased with age,

TABLE 1 SALVAGE OR RESALE VALUE OF USED VEHICLES

	Percent of Original Cost		
Year	Automobiles	Compact Pickup	Trucks and Vans
1	87.0	89.2	89.0
2	74.1	75.1	72.9
3	61.1	61.9	59.3
4	49.1	48.9	45.5
5	35.2	37.0	34.4
6	25.9	26.3	24.9
7	16.7	17.4	16.1
8	9.3	7.7	8.4
9	5.0	5.5	6.0
10	4.0	4.0	4.2

as shown in Figure 2. BMCs include labor, materials, and direct maintenance overhead for routine repair on all vehicle subsystems (e.g., engine cooling, compressed air, accessories, tires, suspension, drive train, electrical, air conditioning and heating, brakes, engine, and body), and inspection and servicing costs. Excluded are the costs of fuel, lubricants, and major subsystem rebuild activities.

The cost curve reasonably reflects the real cost escalation (i.e., the effect of inflation has been removed) of the GMC New Look fleet. Similar curves have been developed for more than 20 bus fleet types and 30 support fleet types used in the United States. The support fleet curve is substantially steeper than the bus maintenance cost curve, reflecting a shorter overall life expectancy.

Application of the vehicle replacement methodology uses the slope of the nationwide maintenance cost curve, the individual operator's wage rate and beginning cost per mile, the local comparative consumer price index, and the operator's fleet mix and running parameters (i.e., mileage, climate, and speed) to develop a BMC escalation curve by fleet. The cost escalation is in terms of FY 1988 constant dollars. The curve would be even steeper if current dollars were used.

Major Subsystem Rebuild Costs

Major subsystem rebuild costs are multiyear operating cost investments that provide additional useful life for transit coaches. Major subsystem rebuilds are usually scheduled events, triggered by fixed mileage intervals. Nationwide, four types of bus subsystem rebuilds occur: engine, transmission, body, and frame. Rebuilds of these subsystems are generally an operating expense, but the expenditure results in additional years of reasonable performance.

Nationwide research includes data on the average number of miles between major subsystem rebuilds and the average cost of each rebuild by coach type. FY 1988 mileage and cost data (on the basis of 170 fleets) are presented in Table 2. These data can be adjusted to reflect each individual operator's practice and experience, or used as is if reasonable.

Annual Equivalent Cost (AEC)

Capital, operating, and subsystem rebuild costs are calculated on the basis of planned or expected retirement age, and spread evenly over each year. For simplicity, all costs are stated in constant-year dollars because Los Angeles County operators did not want to forecast future inflation rates. The AEC approach shown in Figure 3 allows comparison of costs for different durations of useful life.

TABLE 2 NATIONAL AVERAGE FY 1988 DOLLAR COSTS AND SUBSYSTEM REBUILD FREQUENCIES ON THE BASIS OF 170 TRANSIT COACH FLEETS

Vehicle Type	Base Operating Cost Per Mile	Engine Rebuild Miles	Engine Rebuild Costs	Transmission Rebuild Miles	Transmission Rebuild Costs	Major Body Rebuild Miles	Major Body Rebuild Costs	Major Frame Rebuild Miles	Major Frame Rebuild Costs
TMC/RTS 40'	$0.66	240,000	$4,850	120,000	$2,150	240,000	$5,500	270,000	$7,900
FLXBLE METRO 40'	$0.66	240,000	$4,850	120,000	$2,150	240,000	$5,500	270,000	$7,900
NEOPLAN 40'	$0.76	240,000	$4,850	120,000	$2,150	240,000	$5,500	270,000	$7,900
CARPENTER 30'	$0.57	200,000	$4,850	100,000	$1,200	200,000	$6,700	200,000	$2,800
GMC 40' or 35'	$0.66	225,000	$4,300	80,000	$1,900	270,000	$5,200	270,000	$4,900
AMG/MAN 60'	$0.92	180,000	$5,900	90,000	$2,800	300,000	$6,800	360,000	$6,400
GILLIG 40'	$0.65	240,000	$4,850	150,000	$2,150	200,000	$6,700	200,000	$2,800
FLYER 35' or 40'	$0.76	240,000	$4,850	150,000	$2,200	240,000	$6,700	270,000	$2,800
ORION 30'	$0.57	240,000	$4,850	150,000	$2,150	300,000	$6,700	300,000	$2,800
AMG 40'	$0.93	200,000	$4,850	100,000	$2,550	200,000	$6,700	150,000	$2,800
MCI 40'	$0.66	240,000	$4,850	150,000	$1,900	240,000	$5,200	270,000	$4,900
EAGLE 40'	$0.78	320,000	$5,000	200,000	$2,350	360,000	$6,750	360,000	$2,850
GMC/RTS	$0.66	180,000	$5,000	120,000	$2,350	240,000	$6,750	240,000	$2,850
FLXBLE 870	$0.65	200,000	$4,850	120,000	$4,900	240,000	$6,700	240,000	$2,950
Gillig/Neoplan	0.94	200,000	$4,850	100,000	$1,300	240,000	$5,500	270,000	$7,900

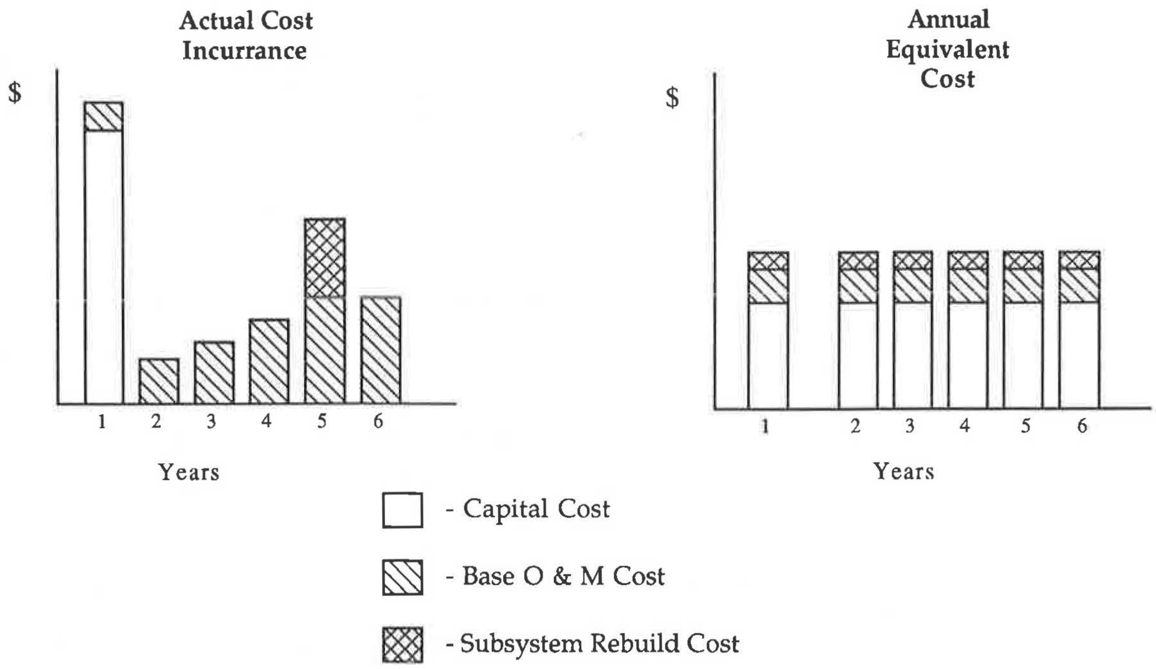


FIGURE 3 Actual cost schedules versus AEC.

The Vehicle Replacement Methodology

The analytic vehicle replacement methodology developed for Los Angeles County transit operators requires 14 straightforward steps to assess the low-cost retirement year. The first four steps develop an AEC for any planned retirement cycle. The subsequent 10 steps define the lowest cost retirement year. An example of the information input required for applying the methodology is as follows:

Long Beach Transit Fleet Data

Fleet type	GMC RTS (4700)
Active buses	13
Annual miles	48,000
Interest rate	8.00%
Purchase price	$93,155
Maintenance cost per mile	$0.66
Engine rebuild miles	180,000
Engine rebuild cost	$5,000
Transmission rebuild miles	120,000
Transmission rebuild cost	$2,350
Body rebuild miles	240,000
Body rebuild cost	$6,750
Frame rebuild miles	240,000
Frame rebuild cost	$2,850

The mileage and cost data presented in Table 2 may be used to supplement local information if all elements are not readily available. The initial four steps in the transit coach replacement methodology are as follows.

Step 1: Determine Annual Capital Cost (ACC) per Vehicle

The first step is to determine the ACC per bus in the specific fleet being analyzed. (Note that each fleet or vehicle type is analyzed separately.) This quantity is a function of the initial purchase price, the salvage value, the expected useful life, and the long-term interest rate.

As part of the AEC approach, the total purchase price is amortized over the vehicle's useful life. The ACC is actually incurred in a single year, but the expenditure is deemed an investment with value (both capital and imputed interest) consumed annually over the useful life. Also, the salvage value is gained in a later year and must be discounted to current-year dollars. The imputed interest rate used for the purposes of this analysis is the long-term U.S. Treasury bill rate, as reported by local newspapers.

The equation for calculating the ACC is

$$\begin{aligned} \text{ACC} = {} & (\text{initial purchase price} * \text{amortization factor}) \\ & - (\text{salvage value} * \text{sinking fund factor}) \end{aligned}$$

Step 2: Calculate Annual Basic Maintenance Costs (BMCs)

For the purposes of this application, the annual BMCs include all vehicle maintenance costs except for fuel and lubricants, which do not have a statistical correlation with vehicle age, and major subsystem rebuild costs. This breakdown is sometimes difficult to derive from local transit operator records. Nationwide data for cost figures by vehicle type presented in Table 2 can be adjusted to local conditions.

The beginning-year maintenance costs are applied to the cost growth formula accounting for real-cost increases related to vehicle age. All maintenance costs are stated in current-dollar terms without adjustment for future inflation. The cost formula is based on mileage driven and accumulated at retirement.

$$\text{BMC}_m = \left[1 + \left(\{[(\text{cumulative miles at retirement} - \text{average miles per year})/100{,}000]/2\} * 0.0353\right)\right] * (\text{initial cost per mile}) * (\text{average miles driven per year})$$

If bus mileage information is not available, annual information can be used, as follows:

$$\text{BMC}_a = \left(1 + \{[(\text{useful life in years} - 1)/2] * 0.0116\}\right) * (\text{initial cost per year per vehicle})$$

This formula assumes about 33,000 mi per vehicle per year, through retirement. The cost escalation factor of 0.0116 can be adjusted to reflect different mileage accumulation rates.

Step 3: Determine Subsystem Rebuild Costs

Subsystem repair and rebuild costs change directly with vehicle age (i.e., the accumulation of mileage rather than years) and are calculated separately. This step requires two calculations, first determining the total subsystem rebuild cost:

$$E = \sum_{j=1}^{4} (\text{average cost of rebuild}_j) * (\text{cumulative miles at retirement})/(\text{miles between subsystem rebuild}_j)$$

where j represents each rebuild type (i.e., engine, body, transmission, and frame). Note that the ratio of cumulative miles to miles between subsystem rebuilds should be rounded down to the nearest whole number before multiplying by cost. The second step is calculating

(Total major rebuild cost)/(useful vehicle life)

Step 4: Determine Current AEC Bus Cost

The results of Steps 1, 2, and 3 are added to determine the total AEC for the existing bus replacement practice. Multiplied by the number of buses in the fleet, this value determines total current AEC.

$$\text{AEC}_t = (\text{annual capital cost} + \text{basic maintenance cost} + \text{subsystem rebuild cost}) * (\text{number of buses in fleet})$$

Comparison of Bus AEC Costs

These four steps can be applied for the range of potential vehicle replacement years (e.g., 8 to 24 years), and the relative AEC cost compared for each year. Application of the Long Beach Transit GMC RTS fleet data presented in Table 3 yields the AEC cost curve shown in Figure 4. As shown, the lowest cost replacement period for this fleet is 15.5 years. In the case examined, all four subsystem rebuilds are scheduled to occur around that time period, should the vehicle be retained. Should the vehicle continue in service, at no time will the average

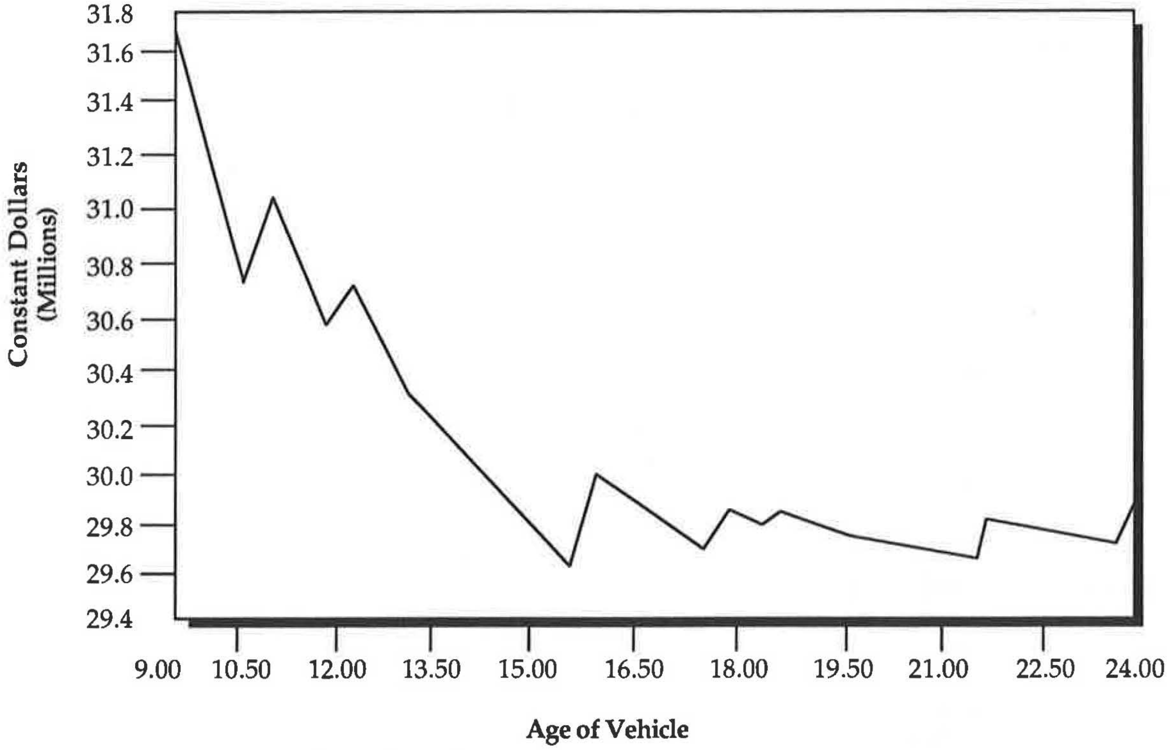


FIGURE 4 AEC of different fleet retirement schedules for Long Beach Transit's GMC RTS fleet.

AEC be less than it is at 15.5 years. When Long Beach Transit planning staff reviewed these results, they indicated that maintenance management had noted that significant expenditures were required to maintain this fleet in the 15th year, and requested direction on the retirement issue. Long Beach Transit frequently operates vehicles for more than 18 years, albeit earlier retirement may be warranted from a cost perspective.

When the replacement guidelines were applied to each fleet owned by the 13 Los Angeles County transit operators, the guidelines presented a less costly replacement alternative, which required replacing the vehicle 2 to 4 years earlier or later than planned. The net result of the new replacement plan is a cost savings of $117 million (FY 1989 dollars) over 10 years.

Another critical benefit of the vehicle replacement methodology is that it brings together all aspects of fleet management. Vehicle replacement, subsystem rebuild, and routine maintenance are all assessed in the overall fleet and cost management decisions. Maintenance, planning, grants, information systems, finance, accounting, and top management all converse and have input into a logical and defensible vehicle replacement strategy. Managers at each level are required to evaluate the full field of issues that impact vehicle replacement.

- Should vehicles operate more or fewer miles to correlate low-cost opportunities with funding availability?
- Should fleets be redeployed to better realize the low-cost opportunities of each specific fleet type?
- Should fleets with problems be lightly used (extending their lives) or should their use be accelerated to speed up retirement?
- Should maintenance practices be changed relative to subsystem rebuild practices?
- Can vehicle procurement practices be streamlined to ensure that costly replacement delays do not occur?
- Given the opportunity for cost savings, can the availability of investment resources be influenced to reduce cost?

These questions are just a few of the questions that Los Angeles transit operators are bringing up in response to the established vehicle replacement guidelines.

Another 10 steps are used to evaluate the Los Angeles fleet strategies. These additional steps mathematically define the low-cost replacement point without the need for applying the initial four steps repeatedly. The additional formulas also allow the operator to schedule mileage accumulation over a curve, rather than only a flat number of miles operated per year over the fleet's useful life. This feature can be important as many new fleets operate high mileage in the early years, and significantly fewer miles toward retirement. Even so, the first four steps afford a sound and simple means of evaluating vehicle replacement schedule alternatives from a comprehensive cost perspective.

DIAL-A-RIDE AND SUPPORT FLEET METHODS

The Dial-a-Ride and support vehicle methodologies focus on BMCs and ACCs—major subsystem rebuilds are not common with these fleets. When rebuilds occur, they are included in the BMCs. Again, the vehicle replacement methodology attempts to define the low total cost replacement cycle.

For each fleet type, the data required for support and van fleets include fleet size, purchase price per vehicle, average annual miles, accumulated miles at retirement (optional), and maintenance cost per mile. The analytic vehicle replacement methodology for support fleets requires the repetition of three straightforward steps.

Step 1: Determine ACC per Vehicle

Unlike transit coaches, support fleets may have a significant residual or salvage value at retirement (Table 1). The ACC per vehicle is

$$\begin{aligned}\text{ACC} &= (\text{initial purchase price} * \text{amortization factor})\\ &\quad - (\text{salvage value} * \text{sinking fund factor})\end{aligned}$$

Again, the salvage value, sinking fund, and amortization factors should be based on the expected useful life of the vehicle and the current long-term T-Bill interest rate.

Step 2: Calculate the Vehicle Annual Maintenance Cost (AMC)

As with the transit coaches, demand response and support fleets also cost more to maintain as they age and accumulate miles. The AMC for vans and support vehicles includes all vehicle maintenance and rebuild costs except for fuel and lubricants. The cost formula for AMC as the vehicle ages is

$$\begin{aligned}\text{AMC}_m &= \{1 + [(\text{useful life}/2) * \text{age factor}]\}\\ &\quad * (\text{initial cost per mile}) * (\text{average miles per year})\end{aligned}$$

If mileage information is not available, annual information can be used.

$$\begin{aligned}\text{AMC}_a &= \{1 + [(\text{useful life}/2) * \text{age factor}]\}\\ &\quad * (\text{initial cost per year per vehicle})\end{aligned}$$

The age factors used in the formulas are as follows:

- Vans: 0.0300
- Automobiles: 0.0167
- Trucks: 0.0213

Step 3: Determine Current Vehicle AEC

The results of Steps 1 and 2 are summed to determine the total AEC for the existing vehicle replacement practice. This value is multiplied by the number of vehicles in the fleet to determine total current AEC cost.

$$\begin{aligned}\text{AEC}_t &= (\text{annual capital cost} + \text{basic maintenance cost})\\ &\quad * (\text{number of vehicles in fleet})\end{aligned}$$

This cost is to be compared with alternative vehicle replacement cycle costs. A simple approach to finding the lowest

AEC cost alternative is both to increase and decrease the replacement year period in Steps 1 and 2. If either change results in a lower AEC cost than the current schedule, continue to increase or decrease correspondingly until the cost trend reverses. The lowest cost cycle will be the year preceding the reversal.

Unlike bus replacement for which the most common low-cost result is to extend useful life modestly, support fleet analysis suggests that retirement and resale be accelerated. There are several reasons for this result in Los Angeles:

- Most operators replaced support fleets after 100,000 mi or 5 years.
- Operating costs increase rapidly for support vehicles, particularly in Years 4 and 5.
- Resale values are high in early years, but rapidly diminish in Years 4 and 5.

In most cases, a 3.5- to 4-year retirement period yielded the lowest total cost for support vehicles. In mileage terms, this choice reflects about 55,000 to 65,000 mi per vehicle in Los Angeles. Overall, the replacement guidelines identified about $8 million (FY 1989 dollars) in cost savings over the next 10 years.

ONGOING VEHICLE REPLACEMENT RESEARCH IN LOS ANGELES

Los Angeles transit concerns with regard to vehicle replacement and meeting of anticipated funding shortfalls are not fully resolved. This study provides only part of the solution. The LACTC, 13 transit operators, and consulting team are continuing to refine and implement solutions to vehicle replacement needs. Ongoing discussions focus on ways to use the guidelines in establishing priorities for capital funding requests among operators in Los Angeles County, identifying and analyzing alternative capital financing mechanisms that overall will help realize the greatest cost savings, and refining and automating the replacement guidelines.

Automation of the guidelines allows the opportunity for greater sophistication without further encumbering scarce staff and data resources. Some enhancements under consideration include

- Developing an algorithm that allows analysis of alternative funding mechanisms and their cost, when attempting to replace vehicles at the low-cost time interval and when sufficient funds are unavailable.
- Changing the maintenance cost formula mathematically to better reflect real cost incurrence, which is an *S* curve, rather than the straight line used in the manual method presented here. Warranties result in low initial vehicle maintenance costs, then normal real cost escalation occurs, and finally costs taper off in the final 2 years of vehicle life as some repairs are foregone.
- Revising the subsystem rebuild function to allow for different rebuild strategies in later years.

Although work continues in the area of vehicle replacement strategies in Los Angeles and across the country, as an industry transit operators and funding agencies should closely examine vehicle replacement decisions from a total cost containment perspective. This process requires examination of the full gamut of fleet deployment, utilization, maintenance, and procurement practices.

ACKNOWLEDGMENTS

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Benefits to Bus Operators of Introducing a Comprehensive Life Cycle Costing System: A Practical Application

HENRY HIDE, TOIVO MADRUS, AND KIRBY JANG

Life cycle costing is an explicit method for evaluating the total cost of an asset over its whole life. It is most useful for equipment whose past purchase costs are comparable in real terms to the acquisition price. The application of life cycle costing to bus fleet purchase, replacement, and maintenance costing leads to more efficient resource control and investment management decisions. An overview of the life cycle costing system is applied to a bus fleet and the inputs needed and outputs available are listed. The technique is applied to a commuter bus company. The application of cross sectional and time series analysis to a partial data base demonstrates how robust results can be obtained from limited information, leading to the identification of significant cost savings in both operating and purchasing decisions.

Life cycle costing (LCC) analysis is an explicit method for evaluating purchase options, taking into account the major costs of an asset over its whole life. These costs consist not only of the initial price but also of the costs of owning, operating, and maintaining the equipment. The concept was initially developed some 20 years ago for equipment procurement decisions at the U.S. Department of Defense.

The application of LCC to investment decisions should lead to efficient purchasing and maximum value for money in the broadest sense. Almost by definition, the technique is most useful for equipment the post-purchase costs of which are comparable in magnitude to their acquisition price. Motor vehicles are ideal subjects for this kind of analysis because they contain a large number of moving parts that interact in a complex manner over a number of years. Whenever they are used, they consume fuel, lubricants, and tires, and the moving parts are subject to wear, which in most cases will require repair and eventual replacement. Vehicle maintenance incurs expensive and often skilled labor as well as the purchase of replacement parts from the manufacturer.

Depending on the life of the vehicle and the scale of the post-purchase costs, differences in the initial price of competitors' vehicles might be small compared with differences in the life cycle cost. In addition, the initial prices and the LCCs may not be correlated or may even be negatively correlated; that is, the vehicle with the lowest purchase price is the most expensive to maintain, and vice versa. Intuitively, this relation suggests reasonable grounds for paying a higher price for a better quality, more enduring product. This potential tradeoff makes LCC an essential part of the investment decision.

A great deal of literature (e.g., *1–18*) already exists on the subject of life cycle costing, some referring directly to LCC and some addressing the concept by implication through, for example, management information systems, vehicle maintenance efficiency, and vehicle operating costs.

Figure 1 shows a simplified cost structure over a vehicle life. The sum of the two crossing curves shows high costs in the early years because of the high initial capital cost, and in the later years because of high maintenance costs. In between, the total annual costs reach a minimum whose position is determined by the relative positions of the capital and maintenance cost curves.

The position of the capital curve is determined by the initial purchase price and the resale values annualized over the vehicle life; a lower purchase price would shift the whole curve down and to the left. Similarly, a reduction in maintenance costs would shift that curve down and to the right. Both of these examples would result in a lower minimum life cycle cost (at different vehicle ages) and would therefore be of interest to a purchaser of vehicles.

LCC analysis is invaluable for making purchase decisions, but for other reasons as well. The methods and data requirements of LCC embrace a wide range of operating practices, accounting conventions, costing systems, and vehicle replacement policies. As these change over time, which they tend to do with the increasing need to monitor costs and with the introduction of computer-based data systems, there will be a general increase in organizational efficiency.

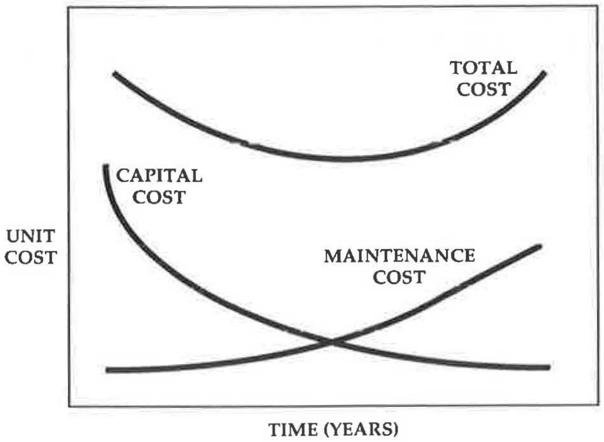

FIGURE 1 Simplified LCC structure.

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A LIFE CYCLE SYSTEM FOR ONGOING PLANNING AND MONITORING OF THE VEHICLE FLEET

The key feature of a comprehensive LCC system is the information provided by the vehicle operating cost data base. This should be an ongoing, continuously updated, cumulative costing system, providing a level of information that can be used to monitor in detail current vehicle operating costs on a component basis. The system can then be used to determine the lifetime performance both of individual vehicles and vehicle types on different route types and sectors.

Although individual organizations may have differing requirements as to how operating cost data should be assembled and presented, the basic framework is that presented in Table 1. The component parts of the framework include

- Vehicle purchase cost;
- Resale value;
- Annual miles run;
- Total miles run;
- Fuel consumed, quantity and cost;
- Oil and lubricants consumed, quantity and cost;
- Cost of spare parts (materials);
- Cost of major component replacement and major structural work;
- Number of labor hours, total and cost; and
- Tires consumed, quantity and cost.

The information is normally updated on a monthly basis, which in addition to giving cumulative costs, shows cost trends by component, and seasonal and usage variations.

TABLE 1 BASIC LCC FRAMEWORK

YEAR	CAPITAL COSTS		MAINTENANCE COSTS		MAJOR COMPONENTS AND STRUCTURE	OPERATING COSTS	
	purchase	resale	materials	labour		fuel	tires
1							
2							
3							
4							
5							
.							
.							
.							
.							
.							
.							
.							
LAST YEAR							
TOTAL							

YEAR	ANNUAL COSTS	ANNUAL MILES RUN	CUMULATIVE ANNUAL COSTS	CUMULATIVE ANNUAL MILES	CUMULATIVE COST / MILE
1					
2					
3					
4					
5					
.					
.					
.					
.					
.					
.					
.					
LAST YEAR					
TOTAL					

Additional information that can be added as required includes

- Time since major component change (e.g., engine or transmission);
- Time since major structural work;
- Availability (in days per month or year);
- Utilization (in hours per day, month, or year);
- Number of in-service breakdowns (per month or year); and
- Ratio of downtime to vehicle availability.

When the comprehensive data system is on stream, it is then available for use both in short-term monitoring of individual vehicles and longer term assessment of vehicle availability, usage, and replacement strategies.

1. *Short-Term Vehicle Monitoring*. Using the monthly records generated by the operating cost component, data files for each vehicle can be interrogated for changes in unit consumption rates that may indicate that problems are arising in certain areas. For example, an increase in fuel consumption per mile when there is no change in the operating conditions of the vehicle suggests there may be a fault in the engine; a reduction in the life of a brake component may suggest either a misassembly or poor quality brake material. The latter could have a significant fleet cost implication if not identified at an early stage.
2. *Longer Term Vehicle Assessments*. In order to carry out these assessments, it is necessary to compute the LCC for each type of vehicle operated by the company. To obtain a perfect LCC for an individual vehicle, it would be necessary to keep records of all costs incurred by the vehicle over its full life. In addition, price indices for each component would be required for each year to convert all historical costs to a common base year. In practice, the most convenient way to obtain the information required is to work within each individual bus type and use cross sectional data from vehicles of different ages within the type over a reduced time period to build the table. An advantage of this approach is that it avoids the problem of having to reconcile cost information from an extended period of time. Using the cross-sectional approach, the ideal situation is that in which the vehicle fleet is large enough to contain individual vehicles of every age, from new to retirement, so that the cost matrix can be built from a single year's data. In practice, this is unlikely to be the case, but it is usually possible to provide sufficient data for the matrix so that the missing years can be filled satisfactorily by interpolation.

With the data matrix complete and all historical costs converted to a base year, the LCC can now be computed. The first step is to discount all costs occurring afterwards back to Year 1.

Costs that will accrue in future years must have a discount factor applied to them to properly reflect their present value, because of the time value of money. Thus the present value of a sum of money due in the future is determined through the application of a discount factor reflecting the cost of money to the organization.

Using the discounted cost matrix, the costs are summed over a given period of time and divided by the total number of miles run over the same period to give the average cost per mile of the period. This calculation is repeated for different time periods to find the time period over which the cost per mile is a minimum. This time period is the optimum life of the vehicle in economic terms and is the age at which the vehicle should be replaced.

With the LCC matrices available for each vehicle type currently in operation, it is possible to interrogate them to obtain information for long-term planning and monitoring purposes. Some major uses in this category include

- Monitoring the performance of individual buses against the fleet type average, to identify any units with consistently above or below average unit costs. Such units could be candidates for early retirement or extended use.
- Assessing the implications of future demand patterns on the ability of the current fleet to meet these demands. The need for additional capacity through early purchase of new buses or short-term hire from outside contractors can be assessed.
- Phasing in new bus purchases to match the economic timing to the availability of finance. It is often necessary to spread the purchase of replacement units over a number of years when a large number of vehicles reach retirement age at the same time.
- Deriving performance levels against which potential new vehicle suppliers can be asked to base their bids. Improvements in engine efficiency and structural life are two items that will have high cost and availability impacts.

Additional concerns will be identified as important by individual operators with different route systems and operating philosophies and constraints.

THE GO TRANSIT STUDY

In August 1987, GO Transit in Toronto initiated a preliminary LCC study of the GO Transit bus fleet, using a partial data base available from an upgraded data system that GO Transit had put in place only 18 months earlier. The work program included the following components:

1. Reviewing the current bus fleet retirement criteria;
2. Identifying optimum economic retirement age for different vehicle types;
3. Comparing the performance of different bus types; and
4. Determining the financial penalties of operating unsuitable vehicles, retiring a vehicle type too early, delaying replacement of a vehicle type with a technically superior model, and introducing an expensive vehicle refurbishment policy.

GO Transit operates an interregional commuter bus system serving the Toronto commuter area within a radius of approximately 60 mi. At the time of the study, GO Transit was operating a heavy-duty diesel bus fleet of 200 units. The main body of vehicles conforming to GO Transit service design consisted of MCI highway buses, GM modified transit buses, and GM transit buses. These vehicles were identified as Types A, B, and C, respectively, in the analysis. In addition, the

Orion 40, an update of the GM Transit bus identified as Type D, that at the time of the study had recently been introduced into service and was being assessed as a possible replacement type, was also included in the analysis. Types A and B operated as highway or longer distance suburban-to-downtown buses, and Types C and D operated as transit vehicles on dedicated routes.

The preliminary study, which was completed in January 1988, proved satisfactory, and GO Transit is currently proceeding with the implementation of a comprehensive LCC system. An outline of the work program to date, including the current study, follows.

GO Transit LCC Study Time Scale

August 1987	Contract let to undertake a preliminary LCC study of the GO Transit bus fleet using a partial data base.
December 1987	Completion of preliminary study and delivery of study reports to GO Transit.
February 1989	Contract let to undertake Stage 1 of the comprehensive LCC and cost benefit projection of the GO Transit bus fleet, designed to identify and recommend the activities to be undertaken in Stage 2 to develop a full-scale LCC system.
April 1989	Completion of Stage 1 of the comprehensive study and delivery of the study report to GO Transit.
January 1990	Commencement of Stage 2; a comprehensive study to develop and deliver a full-scale bus LCC system to GO Transit.
October 1990	Estimated date of study completion and system delivery.

Data Base Assembly

The starting point of any LCC analysis is to identify how much of the basic LCC framework can be filled from the data available.

In an ideal situation, either a complete life history of a sufficient number of units of each bus type would be available (time series data), or the fleet would include units varying in age from 0 to (say) 20 years for each bus type with cost information available for a recent time period (cross-sectional data). In practice, it is unlikely that either of these alternatives would ever be available, leaving the more usual situation of a combination of partial information only. In this situation, the sample size and composition are dictated by the actual data available.

Previous work on vehicle operating costs identified 12 months as the most satisfactory period over which to aggregate vehicle operating costs. A 12-month period is sufficiently long to capture the real change in maintenance costs and utilization levels with increasing vehicle age, and sufficiently short to avoid problems with changes in unit costs of vehicles, parts, fuel, and tires. In the GO Transit study, the most recent 12-month period of the available 18 months of information was chosen and all costs have been converted to 1989 prices on the basis of relevant price inflation figures for vehicle and mechanical items.

The data availability for this investigation are presented in Table 2; and the basic data set is incomplete. As stated, this situation is not unusual given that few bus fleets are likely to contain vehicles purchased in every year over an extended period. To overcome this defect, a combination of time series and cross-sectional analysis is used to maximize the use that can be made of the available data. The method is to plot the available information and estimate the trend by fitting a curve to the points plotted. In this investigation, time curves for the annual miles run, the accumulated mileage, and the total materials consumed for each vehicle were constructed as shown in Figures 2–4. Using this information, the annual miles run,

TABLE 2 VEHICLE AGE AND USAGE LEVELS BY VEHICLE TYPE

Vehicle Type	Vehicle Age (Years)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	No. of Buses					25				12	5 *		14				
	Ave. 1986 Miles					87,380				76,583	49,700		56,050				
	Ave. Total Miles					449,430				637,535	489,020		805,369				
B	No. of Buses		5								20		4				
	Ave. 1986 Miles		53,920								44,870		31,200				
	Ave. Total Miles		103,641								430,660		538,200				
C	No. of Buses											12	10	10		5	15
	Ave. 1986 Miles											43,191	35,720	35,330		33,740	32,447
	Ave. Total Miles											473,958	517,151	508,682		600,680	621,867

** These Vehicles were purchased second hand and the miles run refers to the current owner only. Actual lifetime mileage is estimated to be 40% higher than these figures.*

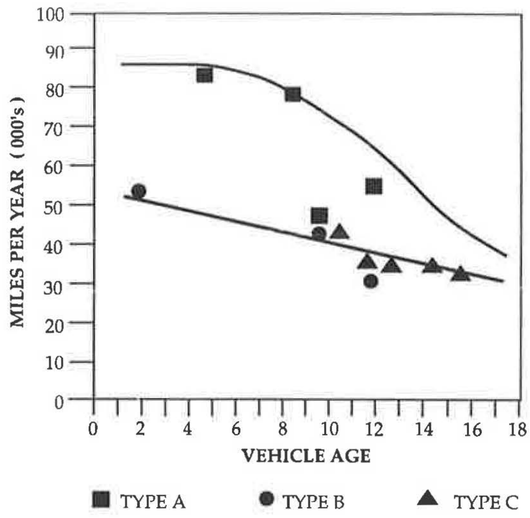

FIGURE 2 Annual miles run (1986) by bus type.

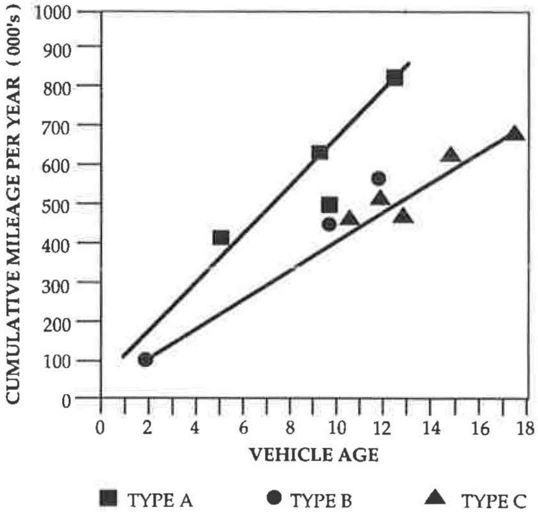

FIGURE 3 Cumulative mileage (ending in 1986) by bus type.

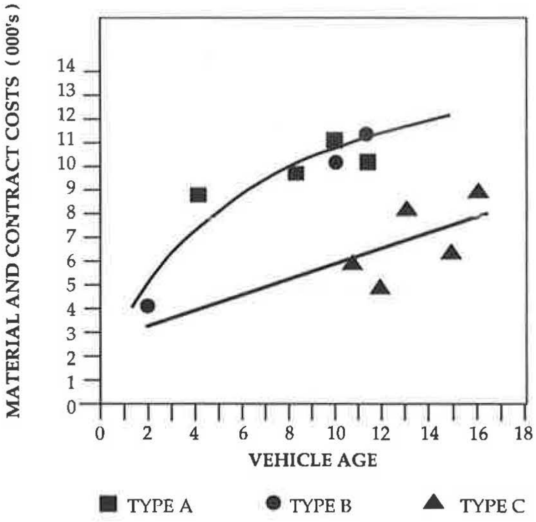

FIGURE 4 Material costs (1986) by bus type.

the accumulated annual miles, and the annual materials cost for each vehicle type were estimated. On the mileage graphs (Figures 2 and 3), Type A buses fall on one curve and the other types on a lower curve, but for the materials cost (Figure 4), Type C buses fall on one curve and the other bus types fall on a higher curve. Lines of best fit have been selected by taking into account the actual points plotted, plus extra information made available on the materials cost and miles run by the new buses brought into operation in 1987, to improve the data available at the low end of the age spectrum. The outcome of this investigation has been interpreted as follows:

- Type A buses fall on the high mileage and high materials cost curves;
- Type B buses fall on the low mileage and high materials cost curves; and
- Type C buses fall on the low mileage and low materials cost curves.

The maintenance labor costs were compared with the materials costs and found to be similar but approximately 7.5 percent greater. They were therefore treated as having age-related curves similar to those of the materials consumed but 7.5 percent higher over the whole range.

In the absence of any detailed information, allowance was made for the cost of the vehicle maintenance facilities exceeding the hourly mechanics cost by doubling the rate. This adjustment, which was decided on after discussions with GO Transit, took into account current commercial and municipal transit garage markups on basic mechanic rates.

A structural integrity body repair program was introduced after 8 years for Type A and B buses and after 12 years for Type C. The program was repeated approximately every 3 years depending on vehicle design and use, and was included in the analysis. GO Transit also undertakes an engine and power train rebuild program. These costs were also included in the analysis.

Fuel costs were provided by GO Transit as a fleet-wide average and were applied to the LCC tables on a mileage run basis.

Contract tire costs also provided by GO Transit for radial and bias tires were also applied on a mileage run basis.

Purchase prices for the buses were obtained from recent quotes received by GO Transit. An estimate of residual values for Type A buses of different ages was obtained by GO Transit. However, little information was available for Types B and C, because of the limited demand for these buses, but values were estimated and agreed on when they were required in the analysis.

Sufficient data were therefore obtained to carry out an LCC analysis for the three bus types. All the LCC calculations were carried for an 18-year period using a discount rate of 8 percent per year. A sensitivity analysis was also undertaken.

Results of the Analysis

In addition to computing the cost per mile at the end of each year, the cost per mile was recalculated for those years when structural integrity and engine rebuild programs were scheduled, omitting these costs. This procedure enabled the option of foregoing the program and retiring the vehicle at the end of the year to be examined.

The results showed that for Types A, B, and C, for which lifetime data were available, the lowest cost bus is Type A, followed by Type B, with Type C the most expensive to operate.

Bus Type	*Optimum Vehicle Age (years)*
A	12
B	18
C	18

Of the three bus types (Types A and B are operated on the same route type and are compared directly), the economic superiority of A was well demonstrated in the analysis. Although the optimum age for the Type A bus is 12 years, the minimum cost after 8 years is less than 1 percent greater than the 12-year cost. Within the limits of accuracy of the data, these two values are not significantly different.

Types C and D are variants of the same type of vehicle, which is designed to carry out a type of operation different from that of Type A. An additional interest in the LCC analysis was to determine the optimum age for replacing Type C by Type D, which is a derivative of Type C with improved fuel consumption and brake component life.

A sensitivity analysis was also undertaken. Each of the cost components was varied by ±10 and ±20 percent in turn and the effect on the LCC of each vehicle type was monitored. The results showed that the LCC computations were robust. There was no change in the optimum age for Types B and C, and although Type A varied between 8 and 12 years, the difference in cost per mile for any particular combination of component costs is a maximum of 1.5 percent only.

The financial implications of the results, presented in Table 3 and shown in Figures 5 through 8, are that

- Operating an unsuitable vehicle type was costing an additional $7,000 per vehicle for each year of operation;
- Retiring a particular vehicle type too early imposed a penalty of $4,000 per vehicle for each year the vehicle was operated;
- An inadequate vehicle refurbishment program was costing an additional $1,000 per vehicle per year, ignoring the effects of reduced vehicle availability and consequent loss of revenue;
- Failure to make an early replacement of a particular vehicle type with an improved model would cost an additional $4,000 per vehicle per year if the older vehicles were operated the full length of their economic life.

The total cost savings of these operating policies amounted to the equivalent of replacing 1.5 percent of the vehicle fleet each year.

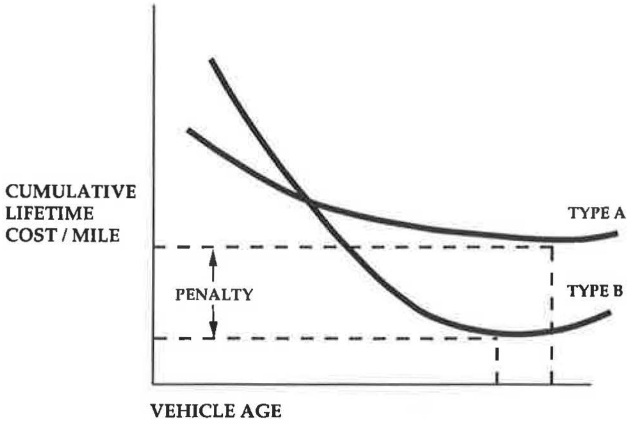

FIGURE 5 Economic effect of purchasing an unsuitable vehicle.

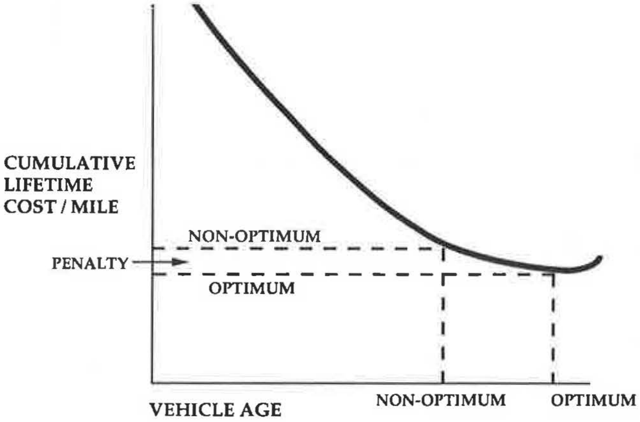

FIGURE 6 Economic effect of retiring a vehicle prematurely.

TABLE 3 COST PENALTIES OF NONOPTIMUM MANAGEMENT AND OPERATIONAL DECISIONS

	COST PER VEHICLE PER YEAR
UNSUITABLE VEHICLE TYPE :	$ 7,000
PREMATURE RETIREMENT:	$ 4,000
INADEQUATE REFURBISHING PROGRAM:	$ 1,000
FAILURE TO REPLACE OLD MODEL:	$ 4,000

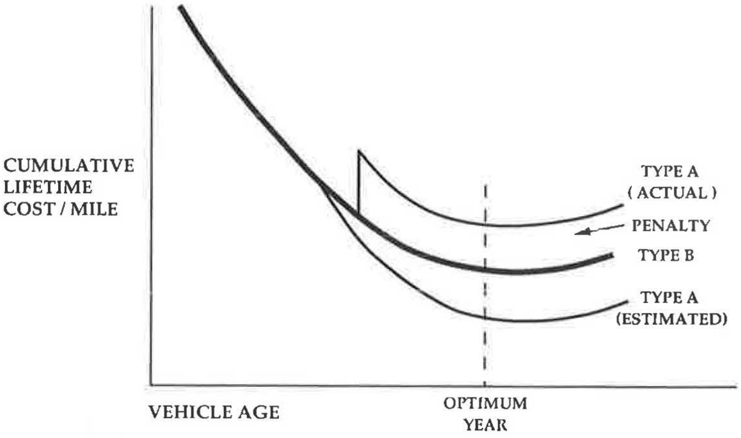

FIGURE 7 Economic effect of underestimating midlife refurbishment requirements.

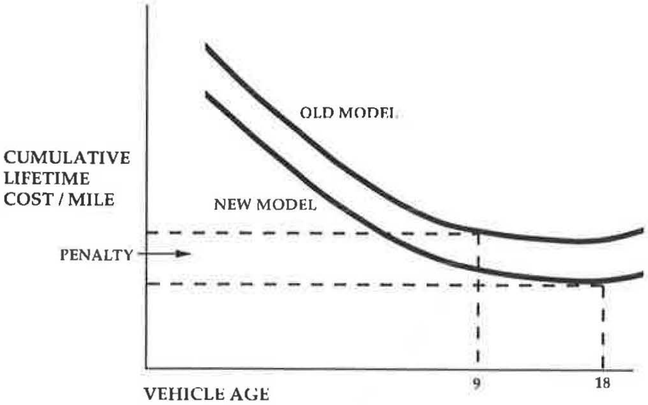

FIGURE 8 Economic effect of not replacing old model.

THE ADVANTAGES OF DEVELOPING A FULL LCC SYSTEM AND DATA BASE

With the availability of the information provided by the data base and LCC analytical system, the bus operator will be in a position to

1. Improve the ongoing monitoring, planning, and budgeting of the bus fleet;
2. Strengthen the management capability through improved information availability;
3. Assess the short- and long-term financial implications both of technical and strategic planning decisions;
4. Reduce the current unit cost of operating the bus fleet; and
5. Provide an improved service to the public at a more economic price.

IMPLICATIONS FOR USE AS A MANAGEMENT TOOL

Because virtually all management decisions have immediate cost implications in a transportation company, management must be able to assess these implications quickly and efficiently.

The implementation of a comprehensive LCC system will give management the ability to monitor current cost trends, predict future costs, and assess the implication of different policy decisions concerning vehicle replacement, route patterns, garaging locations, ridership changes, and financial constraints.

Current Cost Trends

The availability of detailed operating cost information on a continuous basis will enable management to compare actual vehicle expenditures with current forecasts and take appropriate action should any divergence begin. It will also permit the financial implication of any major forced or requested change in the scheduled operating pattern to be assessed.

Future Cost Trends

The LCC system will provide information on the effect of increasing vehicle age on unit operating costs, indivisible expenditures such as engine rebuilds, vehicle refurbishment needs, and vehicle replacement requirements. Future financial demands can thus be programmed to avoid uneven expenditure and ensure either that funds are available as and when they are needed or that expenditures are timed to coincide with the availability of funds.

Vehicle Replacement

A comprehensive LCC system will provide information on the performance and costs of all vehicle types being operated by the organization. This information can be used to assess the most efficient vehicle types for different operating patterns and provide a base case against which potential new vehicle purchases can be compared. It also means that manufacturers can be asked to provide performance guarantees on the basis of the real costs of the current vehicle fleet.

Route Patterns

As the LCC system provides information on the operating costs of individual vehicles, the potential will exist to examine the effect of different route characteristics on revenues and expenditures. It will therefore be possible to assess the fleet requirements for accommodating a potential change in, or addition to, the current route system.

Garage Locations

Any potential change in garaging locations can be assessed both for changes in dead running miles and unit costs of vehicle maintenance resulting from a more efficient maintenance facility.

Ridership Changes

Potential changes in ridership levels, whether local or general, due to rezoning, private travel restrictions, or general changes in demand for public transport, can be costed, and allowance can be made for accelerated or delayed new vehicle purchases and associated changes in maintenance, fuel, and tire requirements.

Financial Constraints

In addition to providing optimum cost solutions, the LCC system will equally well assess the effect of short- or long-term financial constraints and provide a best solution within any particular financial constraint. This solution may take the form of deferred vehicle purchase, increased usage of the current fleet, or hiring in extra capacity on a short-term basis.

SUMMARY

The application of an LCC system to the operation of a transportation company leads to improvements in the efficiency both of fleet purchasing and operating strategies. It enables the performance both of individual vehicles and vehicle types to be monitored and direct operating cost comparisons to be made. In addition to comparing the cost per unit distance traveled, the effect of variations in vehicle availability and use can be assessed, and hence the fleet size required for a particular operation pattern and the revenue earning capacity can be calculated. The combination of information on unit operating costs and vehicle performance characteristics enables the optimum economic life to be computed both for individual vehicles and vehicle types. To purchase the most cost-effective type of vehicle for any particular operation and to monitor individual vehicles within the fleet, both to control particular cost components, such as fuel or brakes, and to identify rogue vehicles at an early stage, are therefore possible.

The information needed for the operation of an LCC system is no more than is normally available within a commercial vehicle operating company. The component costs of operating the vehicle fleet are frequently aggregated by accounts departments for overall company financial control. The only additional resource input required is in setting up a data flow system that ensures that the current information is fed into the basic LCC framework table. This system can be either a parallel activity to the company accounting system, or more efficiently, a stage prior to final aggregated accounting, that will enable a far higher level of financial information to be made available to management for use in strategic decision making.

The benefits to one particular transportation company of introducing an LCC system have been demonstrated to be the equivalent of renewing 1.5 percent of the vehicle fleet per year at no extra cost, in addition to associated improvements in vehicle availability and, therefore, in revenue generation.

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PART 3

Planning

Lindenwold Rail Line and New Jersey Transit Buses: A Comparison

VUKAN R. VUCHIC AND OLAYINKA A. OLANIPEKUN

Rail and bus modes have frequently been compared using theoretical models of hypothetical cities. Because the results of such studies are easily influenced by the author's attitudes toward different modes, there is a need for comparisons of actual transit systems. Two transit systems, rail and bus, serve the New Jersey suburbs of Philadelphia. The conditions under which they operate are generally the same, but the two systems differ greatly. The Lindenwold (PATCO) Line, a single 14.2-mi-long (22.8-km) radial rail rapid transit line with 13 stations, offers high-quality service, including high speed, comfort, reliability, and a strong image. New Jersey Transit (NJT) operates a 562-mi (904-km) network of 26 bus routes on streets, arterials, and freeways, but with low service frequency. Whereas the Lindenwold Line required a substantial investment, NJT buses use existing facilities. The Lindenwold Line attracts 43 percent more passengers and has a 44-percent higher operating ratio in spite of its 20- to 30-percent lower fares. These findings show that concentrated transit service can be more capable of attracting commuters than flexible services that operate on an extensive but low-frequency network. This type of high-quality, intensive service (by rail or bus) also has a much greater potential to influence economic development than the low-investment, extensive bus networks typical for many suburban areas. The results of this study refute the statements that low-investment buses offering flexible services can better satisfy transportation needs in low-density suburban areas than rail systems with limited networks and that new rail transit is not economically justified in most automobile-oriented North American cities. Modern, economically designed rail systems require a considerably higher investment than buses, but they attract many more automobile drivers and other passengers, have superior operating economy, and exert a much stronger positive impact on the communities they serve.

Comparative analyses of transit modes, officially designated as "alternatives analyses," have been performed in recent years in a number of cities, including Pittsburgh, St. Louis, San Diego, Houston, Portland, Ottawa, Calgary, and San Jose. All of these studies lacked experience with different modes in the same locations. One of the basic questions that arises is: Where should each candidate mode (e.g., express bus operations, high-occupancy vehicle or real busway facilities, or rail transit) be used?

RAIL AND BUS SYSTEM COMPARISON: THEORY AND PRACTICE

During the 1960s and early 1970s, a number of theoretical studies comparing modes were published. Most of these studies were sharply disputed for several reasons. First, they were based on hypothetical situations, claimed to be typical for any city. Second, their evaluations were based on minimum cost, whereas differences in quality of service, impacts, and many other important factors were disregarded. Third, they ignored the differences in demands for different modes, although they are often large. Finally, a number of the studies were aimed at finding which mode is better than the others, whereas in reality each mode has its own appropriate application. The question of whether either bus or rail is superior to the other is incorrect to begin with; the relative merit of each system depends on the requirements that have to be met.

Having compared findings of these studies, Deen (*1*) showed the weaknesses of the approaches based on hypothetical cities. Because the models used for these studies are sensitive to various assumptions, the outcomes of such analyses can easily be influenced by the author's attitude toward different modes. Consequently, the results of these studies differed from each other by as much as a factor of 10. Although discredited, hypothetical studies continue to be performed from time to time, often containing the same errors observed before.

Studies comparing planned modes for specific cities are more realistic, because they are based on actual conditions. A remaining problem is that they are still based on projections of the characteristics and impacts of different modes. To get accurate projections (because two or more different modes seldom serve identical corridors), it is necessary to compare different modes serving similar areas in the same or similar cities. A valuable source of information on bus transit systems in different cities was published by Wilbur Smith and Associates (*2*), and Pushkarev (*3*) gave an excellent review of rail transit systems and their roles in U.S. cities. Vuchic and Stanger (*4*) made a comprehensive comparative analysis of rail and bus systems using the specific examples of the Lindenwold Line and the Shirley Busway, which have extensive similarities, so that the differences in their services and impacts can be largely assigned to the characteristics of the rail and bus modes.

COMPARISON OF RAIL AND BUS SYSTEMS SERVING THE SAME AREA

As in the Vuchic and Stanger study (*4*), two existing, operating systems will be compared. However, instead of two systems that in many ways represent the most advanced forms of their modes (the Lindenwold, rapid transit, and the Shirley, express busway), two modes of services in the same suburban

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area—modern rapid-transit and a minimum-investment bus system using streets, arterials, and freeways—are compared. Therefore, new insights on the characteristics of rail and bus transit modes in roles typical for many North American cities should be provided.

METHODOLOGY

The methodology applied here is similar to the one used by Vuchic and Stanger (*4*). The two systems and their characteristics are presented, including both quantitative and qualitative data. Then, the performance and characteristics of the two systems are analyzed by individual parameters, classified into three groups by the interested parties: passengers, operator, and community. The selection of these parameters may vary somewhat with local conditions. The following have been selected as the most important parameters:

Passenger	*Operator*	*Community*
Spatial availability	Area coverage	Quality of service
Temporal availability: Frequency	Frequency Speed	System impacts
Speed or travel time	Control and reliability	
Reliability of service	Costs, revenues, and operating ratios	
User costs		
Comfort	Capacity	
Convenience	Side effects	
Safety and security	Passenger attraction	

On the basis of the comparative analyses of individual parameters, an overall comparison of the two systems is made. Finally, the differences inherent in the two modes are discussed.

SERVICE AREA

Both the Port Authority Transit Corporation's (PATCO's) Lindenwold Line and New Jersey Transit (NJT) buses serve the New Jersey suburbs of Philadelphia (Figure 1). Their major role is to provide transportation between these suburbs and center-city Philadelphia and Camden. They are also used for trips between suburban areas of New Jersey.

Center-city Philadelphia, defined as the area between the Delaware and Schuylkill Rivers and between Vine and South Streets, has an employment of approximately 238,000 and contains stores with some 4.8 million ft^2 (0.45 million m^2) of leased retail area. Downtown Philadelphia also has a large number of restaurants, cultural and historic attractions, sports events, and other activities. As such, it is by far the most dominant generator of trips from the suburbs of the entire Delaware Valley region, which had a population of 5,148,000 in 1987.

Camden, the largest traffic generator in the New Jersey suburbs, was a city with a population of 83,000 in 1987. It is the seat of Camden County; in addition to governmental offices and legal services, it has some light industries and educational institutions.

The suburban area consisting of Camden, Burlington, and Gloucester counties has a number of mature and stable townships, as well as commercial strip developments, industrial areas, and recently developed low-density residential areas. Their overall population densities in persons per square mile (persons per square kilometer) are as follows: Camden, 2,096 (5,426); Gloucester, 589 (1,525); and Burlington, 436 (1,129). Automobile ownership for the three counties is 1.48, 1.58, and 1.65 cars per household, respectively. Thus, these are rather typical, medium- to low-density automobile-oriented suburbs.

The basic data on the service area and the two transit systems are presented in Table 1.

Rail System: The Lindenwold Line

The Lindenwold Line has four stations in center city Philadelphia: one at Market and 8th streets and three along Locust Street, which is parallel to Market, three blocks south. Two of these stations provide convenient transfer to the two rapid-transit lines in Philadelphia. A two-block connection through a shopping mall links the Lindenwold Line to Market East Station, which serves the entire regional rail system, consisting of seven diametrical lines.

In Camden, the Lindenwold Line has two stations in the center city; one is part of a major new multimodal transportation center. From Camden, the line proceeds along a southeast corridor through several municipalities (Collingswood, Haddonfield, and Voorhees), as shown in Figure 2. The seven stations along this section have park-and-ride (P&R) facilities with a total capacity of 12,571 spaces. Lindenwold Station, with the largest P&R facility, has 3,318 parking spaces and a transfer to the National Railroad Passenger Corporation's (AMTRAK's) new Atlantic City line. A detailed description of the PATCO line is given by Vigrass (*5*).

Bus System: New Jersey Transit

NJT is a statewide public transit corporation. It was created in 1979 by an act of the state legislature with the charge to provide transit services throughout the state by operating, contracting for, and subsidizing services in the public interest.

NJT serves Camden, Gloucester, and Burlington counties with an extensive network of 20 lines that encompass 26 routes or branches. These routes are plotted in Figure 1. Eleven major lines with 17 branches converge on Ben Franklin Bridge and proceed to Philadelphia, along Market Street to City Hall, then up to Vine Street and back to the Ben Franklin Bridge. Thus, they serve the city's core with several stops on Market Street between 6th and Broad streets.

NJT bus lines also serve Camden quite extensively; five lines terminate in Camden, and several lines from the suburbs to the Ben Franklin Bridge go through downtown Camden, increasing coverage and service frequency in that area.

As shown in Figure 1, NJT bus lines form an extensive multidirectional network that also provides many trips among suburban townships and commercial areas, in addition to the dominant travel volumes into and out of Philadelphia and Camden. Several of these lines serve as feeders to the Lindenwold Line. The lengths of the lines vary from 7 to 49 mi (11 to 79 km), and the network length is 562 mi (904 km).

The NJT bus network has approximately 1,500 stops in these three counties. There is little demand for P&R, so the

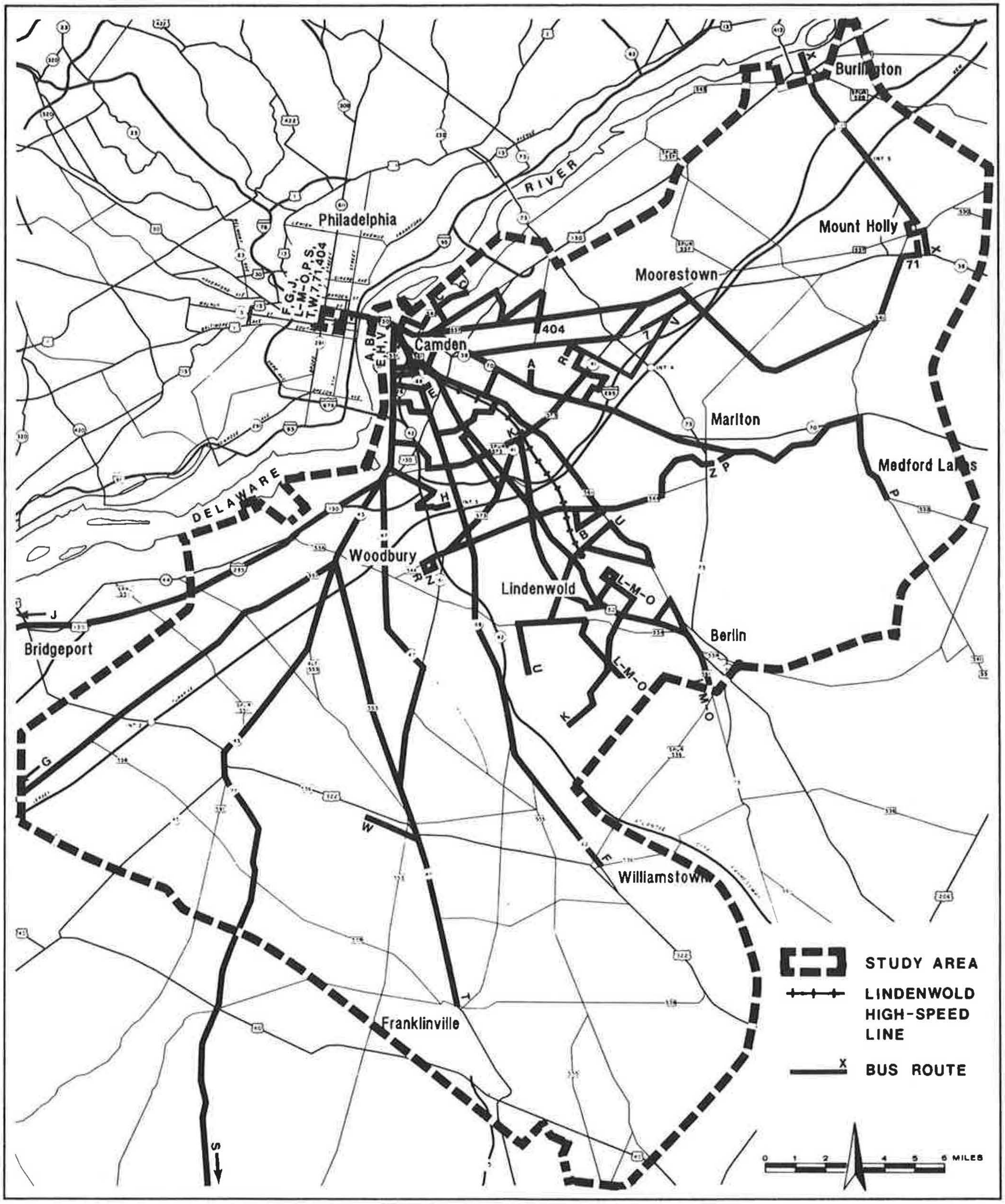

FIGURE 1 Philadelphia-Southern New Jersey study area with the Lindenwold Rail Line and NJT Bus network.

TABLE 1 BASIC AREA AND TRANSIT SYSTEMS CHARACTERISTICS

Characteristic	Lindenwold Rail Line	NJT Buses
Service area	One of several radial corridors in Camden County	Several corridors and most of Camden, Burlington and Gloucester Counties
Area size (mi²/km²)	130/337	593/1536
1980 Population	471,650	794,777
Type of lines	Radial via bridge to Philadelphia	Radials into Camden and via bridge to Philadelphia; cross-town, branches, rail feeders
Technology	Rail rapid	Buses on streets arterials, freeways
Type of service	Local, some express runs	Local and express
Network length (mi/km)	14.2/22.8	562/904
No. of stations/stops	13	~1500
Park-and-ride spaces	12,571	~ 600
Submodal split[%]		
Walk, bicycle	11	63-77
Feeder transit	9	15-28
Kiss-and-ride	43	10-20
Park-and-ride	37	
CBD distribution	4 stations, transfers to SEPTA lines	Stops along 6th and Market East Streets

capacity of P&R facilities is only about 600 spaces; a certain number of transit riders park their cars along the streets in the vicinity of bus stops. Extensive technical details on NJT buses are to be given in a report by NJT (*6*).

Table 2 presents a summary of the operating statistics of the two systems.

COMPARATIVE ANALYSIS OF THE LINDENWOLD LINE AND NJT BUSES

Individual parameters of the two systems will be compared. A parameter (or requirement) will be briefly defined; then each system will be examined with respect to it, quantitatively or qualitatively. Some requirements that are difficult to separate clearly will be evaluated together. The comparisons will be summarized in an overall comparative analysis of the two systems.

Passenger Requirements

Spatial and Temporal Availability

Availability is the basic passenger requirement for transit service use. Three aspects of availability can be defined: first, a person's ability to use a system; second, spatial availability, which involves both the passenger's ability to get to the system and the requirement that the transit service goes to the necessary destination; and third, temporal availability, which is the frequency of service or its inverse, the headway.

Although the availability of automobile travel depends on vehicle ownership and the owner's ability to drive, transit systems are generally available to all persons; in this respect, bus and rail systems are the same. The availability of stations is influenced by the available feeder modes, such as automobiles, bicycles, or feeder buses. For a given trip, the availability of service depends largely on the extensiveness of the

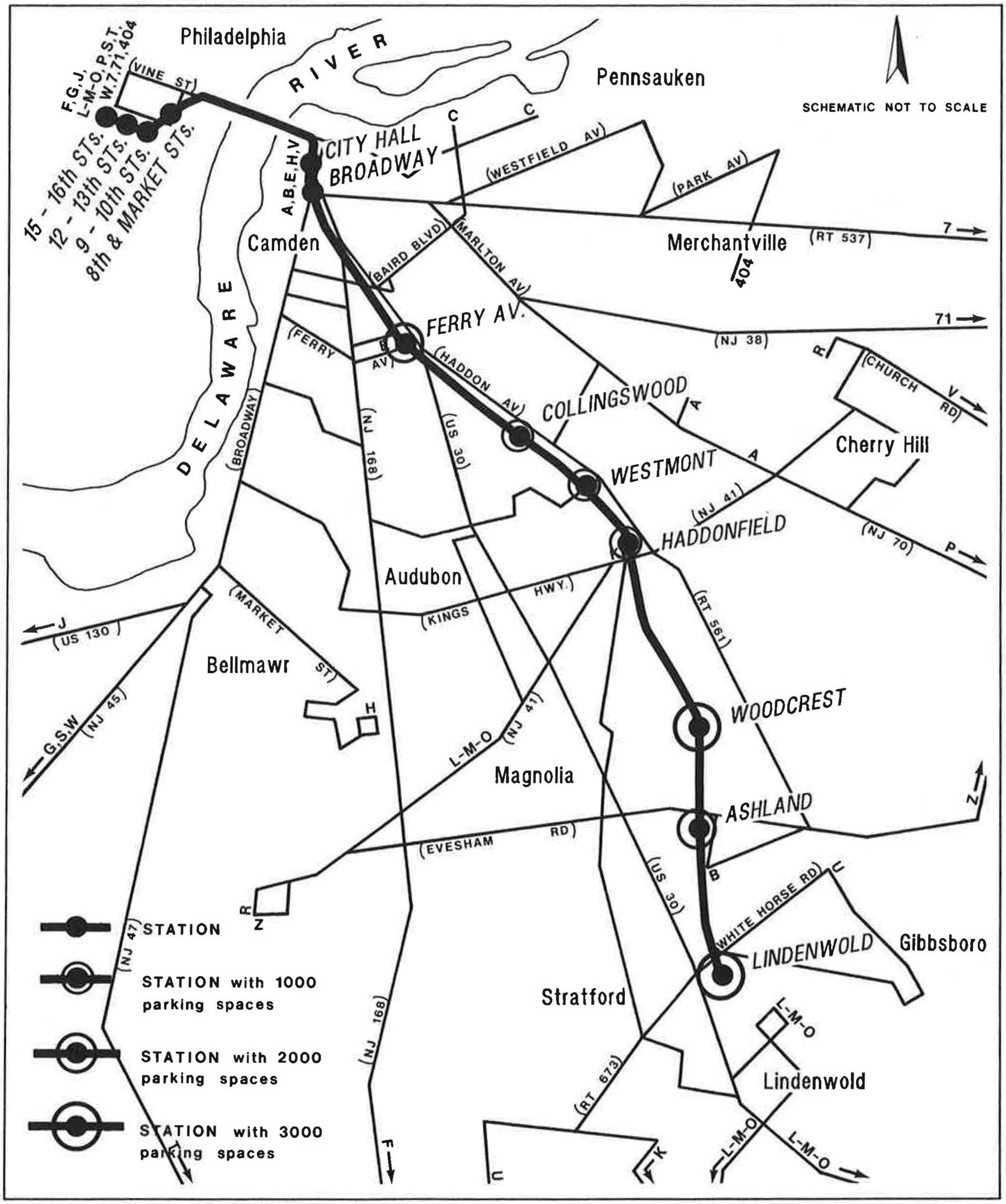

FIGURE 2 The Lindenwold Line alignment with stations and P&R capacities.

TABLE 2 1987–1988 OPERATING STATISTICS: LINDENWOLD RAIL LINE AND NJT BUS SERVICES

Category of Routes	No. of Trunks/ Total Branches	Passengers /Weekday	Cost/Veh-Hour	Revenue/ Veh-Hour	Operating Ratio
Lindenwold Rail Line	1/1	39,500	125.10	97.03	0.78
Philadelphia Commuter	11/17	22,230	40.19	23.31	0.58
Camden Area	5/5	1,661	37.10	12.60	0.34
Camden Locals	4/4	3,725	35.74	17.87	0.50
Total Intra New Jersey	9/9	5,386	~36.00	~16.00	0.44
Total NJT Buses	20/26	27,616	~39.00	~21.00	0.54

transit network. Frequency of service must be analyzed for peak and off-peak hours.

Lindenwold The PATCO Line provides only a line-haul service with few stations. Its outlying section consists of seven stations with an average spacing of 1.5 mi (2.4 km) and the longest spacing of 2.4 mi (3.86 km). For area coverage, this line relies heavily on feeder systems. The most important feeder mode is the automobile, which brings 43 percent of the passengers as kiss-and-ride (K&R) and 37 percent as P&R users. Twenty bus lines (both feeders and regular lines) come to the Lindenwold Line stations at various points on their routes. The transfer is physically convenient, and some discount in joint fares is available. Bus riders, walkers, and bicyclists amount to approximately 11 percent of the Lindenwold Line passengers.

The two stations in Camden, which are downtown, are served by many of the bus lines. In Philadelphia, a short distribution segment is within the center city, but the stations are two to four blocks away from the main employment centers and shopping areas. Convenient transfers and reduced fares provided for transfers to Southeastern Pennsylvania Transportation Authority (SEPTA) lines for inbound round trips tend to offset this handicap.

The Lindenwold Line has an extremely high performance with respect to frequency of service. During the peak hours, some headways are as short as 2.5 min; during the base periods, typical headways are 10 min; and during the owl service at night, 30-min headways are maintained. In addition, some of the peak-hour trains offer limited express runs on individual sections of the line. The line has about a 100-percent reserve capacity, because it can be operated at 2-min headways instead of the present 4-min headways.

NJT Buses The spatial availability of NJT buses is excellent. The network consists of 20 trunk lines branching into 26 routes, with considerable overlapping on individual segments. The exact number of stops is not known, because many stops in outlying areas are rather informal, but the network has an estimated 1,500 stops and stations in southern New Jersey. Because it is so extensive, this network is also good in serving a large number of origin-destination pairs.

In service frequency, the system is poor. The busiest lines offer peak-hour headways of 12 min and base headways of 1 hr; there is no service between 12:00 midnight and 5:00 a.m. The service frequency is considerably better on the sections where several lines overlap for some distance. The maximum frequency (up to 60 buses per hour) occurs on the Ben Franklin Bridge to Philadelphia. This frequency, however, is not significant for passengers, because only a few of these buses will be appropriate for each destination, because of their branching toward New Jersey suburbs.

It is difficult to obtain precise data on the submodal split of passenger access to NJT buses in New Jersey, but surveys have shown that walking accounts for 63 to 77 percent of the access to individual lines; 15 to 28 percent of the passengers transfer from other buses, whereas P&R use is rather negligible. There are several P&R and some unofficial parking areas; their total capacity is estimated to be 600 spaces.

In downtown Philadelphia, NJT buses distribute passengers along Market Street to City Hall and then return via Vine Street to the Ben Franklin Bridge. Thus, the distribution of buses is in the heart of the city, close to many destinations.

Comparison The two systems are drastically different with respect to availability of service. The Lindenwold Line has few stations but an excellent feeder system, dominated by automobile access. The line offers excellent frequency at all times of day. NJT buses, on the other hand, have an extensive network with many lines and stops, but have poor frequency of service (Figures 3 and 4).

Speed or Travel Time

Door-to-door travel time consists of five elements: access, waiting, travel, transfer, and departure times. The relative weights of time intervals vary, because passengers perceive them differently. On the basis of various studies reported in literature, a factor of 2.5 for waiting and transfer times is used here to obtain perceived travel times.

Lindenwold For a typical automobile commuter residing 3 mi (4.8 km) beyond the Lindenwold Station, an average of 47 min are required for the morning peak-hour drive to the Philadelphia central business district (CBD), including parking. The same journey using the Lindenwold P&R or K&R facilities requires 35 actual minutes or 42 perceived minutes. The average travel speed on the line is 35.5 mph (57.1 km/hr); the design speed is 75 mph (121 km/hr).

NJT Buses Average travel speeds on NJT buses range from 12 to 40 mph (19 to 64 km/hr), but they are most often in the range of 15 to 25 mph (24 to 40 km/hr). The time it takes people to access the bus stops is in most cases rather short. However, buses travel more slowly than other traffic because of passenger stops. Moreover, buses are also subject to highway traffic delays. The typical commuter trip analyzed earlier would take approximately 70 min by NJT bus service.

Comparison As the sample trip and Figure 5 show, the Lindenwold speeds and travel times are clearly superior to those of NJT. The Lindenwold Line provides faster service than the competing travel by private automobile, whereas buses are inferior to cars in travel times.

Reliability of Service

Passengers consider reliability, or schedule adherence, as one of the most important elements of transit service. It is measured as the percent of transit vehicle arrivals at their destination within 0 to 5 min of the scheduled time. Reliability depends on many factors, the single most important one being the type of right-of-way: a separated right-of-way always provides a much higher reliability of service.

Lindenwold Having an exclusive right-of-way and good operational control, the PATCO line provides extremely reliable service. From 1980 to 1986, the average punctuality of this service fluctuated between 98.34 and 99.10 percent, which is typical for well-operated rapid-transit rail systems (*7*).

NJT Buses NJT buses operate in mixed traffic, except for a bus lane in center-city Philadelphia. Yet, in a personal interview, an NJT official claimed that the service reliability is between 97.02 and 98.01 percent.

Comparison The PATCO line provides a higher reliability of service, although the difference is not as great as the typical difference between rapid-transit rail lines and buses on streets, because of the good performance of NJT buses.

User Costs

Passengers are sensitive to the direct, out-of-pocket costs they pay for individual trips. Transit fares represent such a cost, as do payments for parking or tolls. Passengers sometimes look also at average total costs. With respect to these costs, the two systems are drastically different.

Lindenwold The Lindenwold Line has a graduated fare that goes from the basic fare of $0.75 to the maximum fare of $1.60. Close-in portions of P&R lots involve a parking charge of only $0.25. Thus, the out-of-pocket costs are low even for most riders who use an automobile for access (i.e., all K&R and many P&R users). However, for the riders who own an automobile only for the purpose of driving to the line, that involves substantial costs. On the basis of U.S. Department of Transportation reports, the average annual costs of owning and driving an automobile amount to approximately $3,000.00, or $8.00 per day. Thus, for the riders who own an automobile only for access to the rail line, the indirect cost usually exceeds the out-of-pocket cost for their travel to Philadelphia.

NJT Buses Bus fares are also graduated, from $0.90 for Zone 1 to $5.20 for Zone 10 (in 1987). The Lindenwold terminal falls in Zone 4, for which the bus fare to town is $2.35 (Figure 6). Thus, the minimum fare on the buses is 20 percent higher than on rail, whereas the maximum comparable fare is 42 percent higher. Because most passengers approach bus stops on foot, however, their indirect cost is much lower than the costs for rail riders.

Comparison The Lindenwold Line involves a considerably lower out-of-pocket cost, but the average total travel cost for its users is higher than for NJT bus riders.

Comfort

The paramount elements of comfort are the availability of a seat and the quality of ride, both of which affect a user's ability to read or write. The physical comfort of the seat, its shape, vehicle entrances and exits, air conditioning, jerk and noise levels, and the image of patrons relative to a user's self-image are also contributing factors.

Lindenwold Although there is ample seating in the vehicles in off-peak hours, in some peak-hour trains 20 to 30 per-

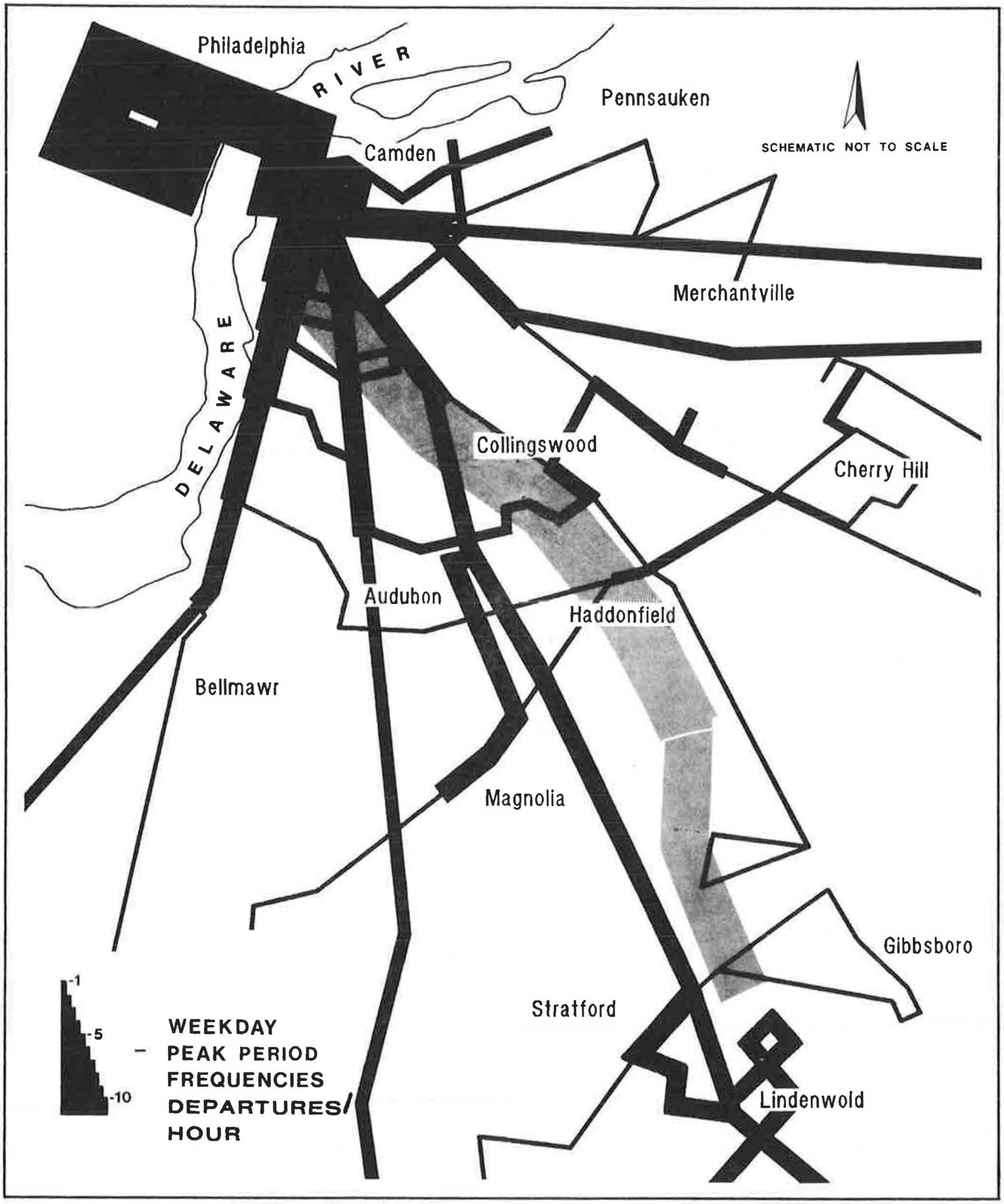

FIGURE 3 Peak-period service frequencies: Lindenwold Line and NJT Buses.

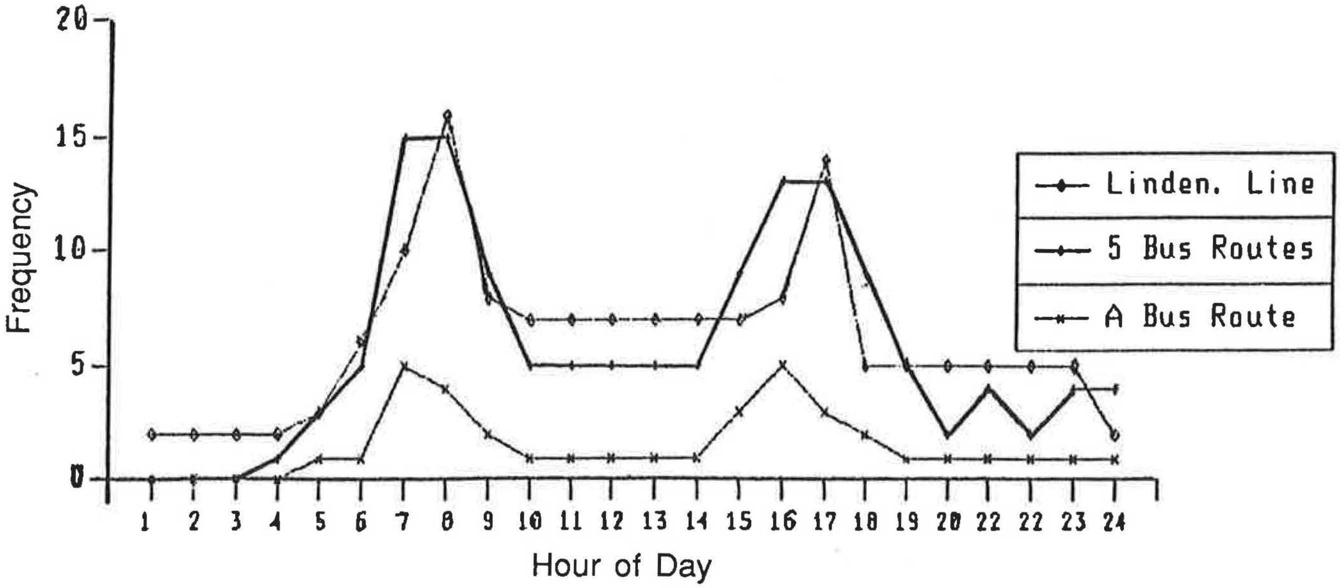

FIGURE 4 Comparison of frequencies during different periods of day.

cent of the passengers stand during about 10 min of travel. The seats themselves are wide and comfortable. The car interiors are plush, air conditioned, clean, and lighted, affording the opportunity for reading. Vehicle acceleration is rapid but smooth. Large windows offer visibility in all directions, contributing psychologically to the attractiveness of this service.

NJT Buses Buses are less comfortable than rail vehicles, because the seats are tighter, the ride is more jerky, and buses are subject to unpredictable influences of other traffic. NJT buses are air-conditioned, and there are usually no passengers standing. The visibility is not as spectacular as that of the Lindenwold Line.

Comparison With the exception of standing, which is more common on the rail line than on the buses, all components of comfort are superior on the Lindenwold Line.

Convenience

Although most components of comfort are related to the vehicle, convenience refers to the overall transit system. Lack of transferring is a great convenience, as are good off-peak service, clear system information, well-designed and protected waiting facilities, sufficient parking (if required), and high quality of service. By its nature, convenience represents a qualitative characteristic of transit systems.

Lindenwold The PATCO line requires a transfer from access modes for 89 percent of its passengers. Parking around stations represents a great convenience to users who come by car. Stations are pleasant and offer convenient access to platforms and a high quality of service. Information about the service is clear, simple, and always available. Thus, although most passengers must transfer from different modes, the convenience of using the PATCO line is excellent.

NJT Buses With its combination of local and express services, NJT offers what is often pointed out as a great convenience of bus services for low-density areas: extensive area coverage and no need for access modes. However, the potential user is faced with the problem of discovering which line goes where, at what time (long headways), where the stops are, and how much he or she has to pay. Thus, the convenience of NJT buses is low.

Comparison The convenience of the large network of bus routes and many stops is greatly outweighed by the convenience of the high-quality service from distinct, well-designed stations with frequent service for which no schedule is needed. Thus, the Lindenwold Line is much more convenient to use than NJT buses.

Safety and Security

Safety generally refers to the absence of accidents; security is protection from crime.

Lindenwold Being a typical modern rail transit system, the PATCO line has redundant automatic safety devices that ensure extremely high operating safety. Except for a few light car collisions in maneuvering and a couple of derailments at low speed, the line has never had an accident. No passenger has been killed on the line by a train accident in the 22 years of its operation. The line's security arrangements include continuous closed-circuit television monitoring of all stations coupled with a public address system, and a police force that guards the station areas and overnight trains. These arrange-

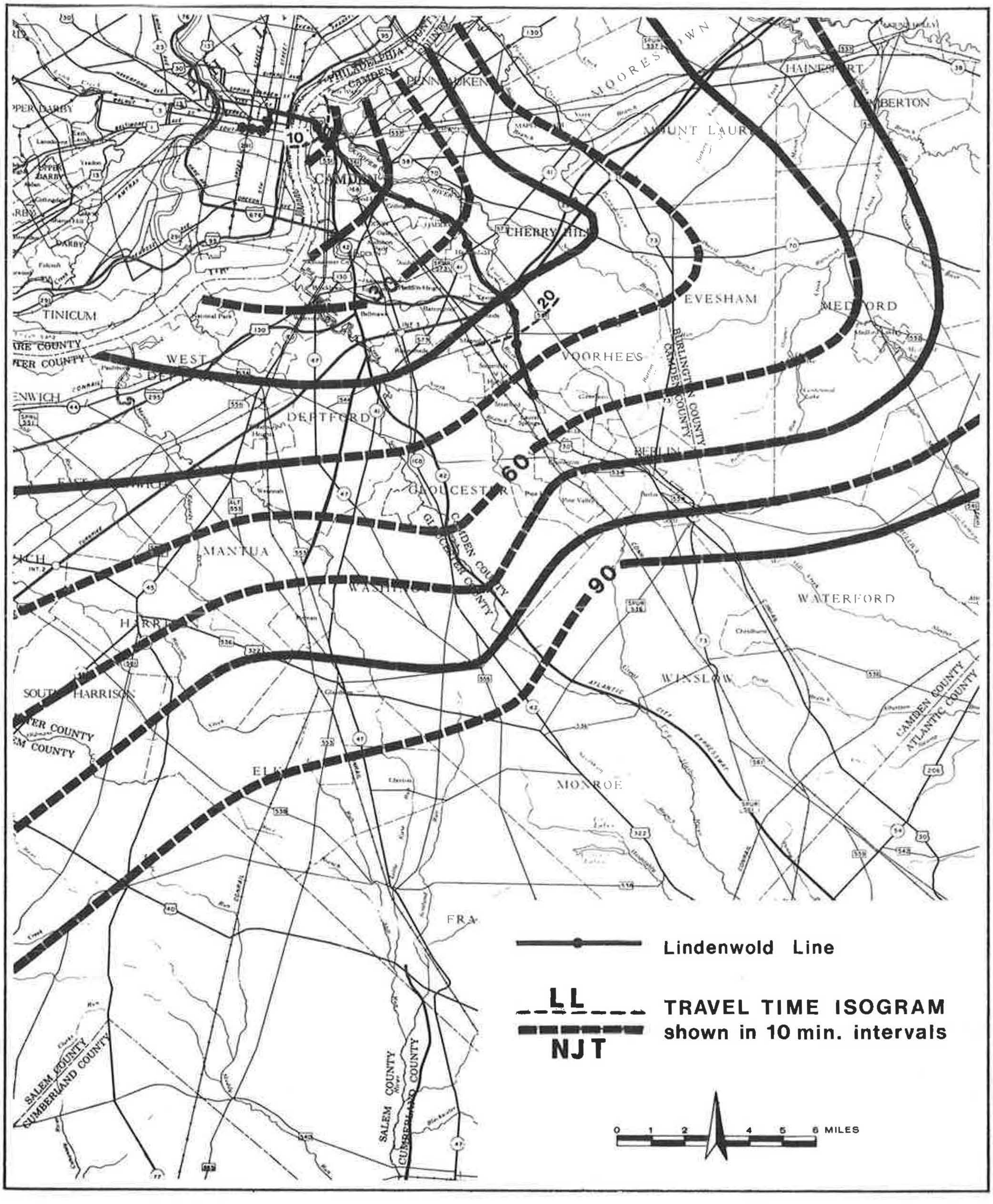

FIGURE 5 Isochrones of travel to Philadelphia CBD by Lindenwold Line and NJT Buses.

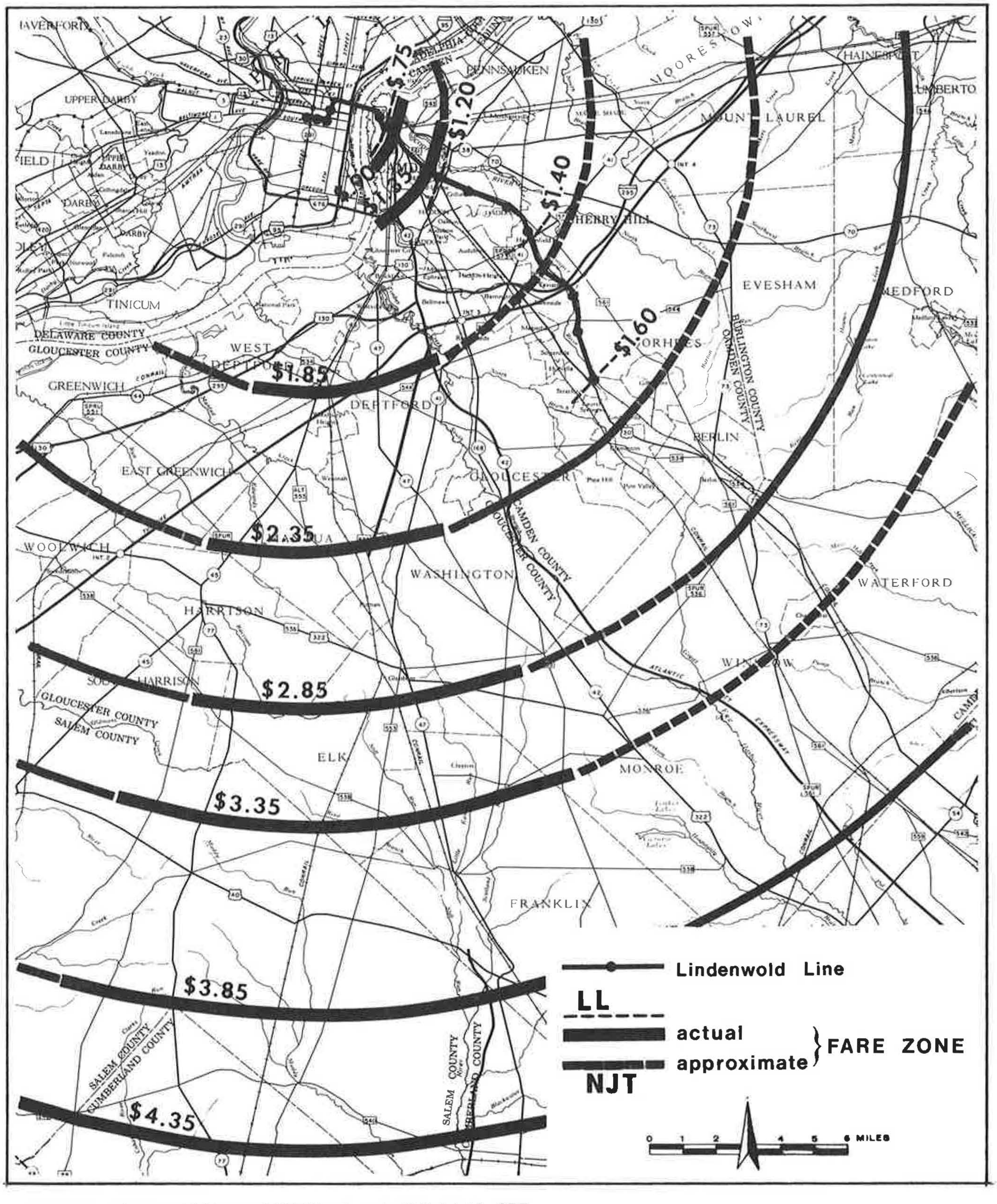

FIGURE 6 Lindenwold Line and NJT Bus fares to Philadelphia CBD.

ments have produced a high security record and good public image.

NJT Buses Although bus service is relatively safe, the buses are in highway traffic and are involved in some accidents. With respect to crime protection, passengers like the presence of the driver in the bus, but waiting for a bus at a curbside location in lonely areas, particularly at night, is a feature that many passengers find objectionable.

Comparison In both safety and security, the Lindenwold Line is excellent. The NJT buses have a good safety record, although not as high as that of the Lindenwold Line; their security has a far lower image.

Operator Requirements

Area Coverage

Lindenwold Taking 5- to 10-min walking distances (i.e., 1,250 to 2,500 ft or 400 to 800 m) as measures of area coverage, the nine Lindenwold stations in New Jersey have a coverage of 1.58 mi^2 (4.10 km^2) or 6.34 mi^2 (16.42 km^2), respectively. However, because nearly 90 percent of its passengers use automobiles for access, it is more realistic to consider the area from which the majority of P&R and K&R passengers come to the stations. Surveys of these passengers (*8*) have shown that they approach the stations from an area of approximately 130 mi^2 (337 km^2).

NJT Buses With their frequent stops along the routes, it can be considered that the area covered by these services represents a strip of 5-min walking distances on each side of the bus routes. Measurements show that the total coverage by NJT buses in New Jersey suburbs amounts to 593 mi^2 (1,536 km^2).

Comparison With the length of all bus routes being 562 mi (904 km), as compared to the Lindenwold Line length of 14.2 mi (22.8 km), the bus network is nearly 40 times more extensive. Its area coverage, even if it is assumed that buses cover only walking distance areas whereas the rail system covers an area of access by automobile, is about 4.5 times greater.

In center-city Philadelphia, buses offer somewhat better coverage, because they follow an alignment through the heart of the city, whereas the Lindenwold Line runs three blocks south of this alignment; on the other hand, the Lindenwold Line offers better integrated transfers to SEPTA's rail network; it can therefore be considered that the distributions of the two systems in the center city are comparable.

In conclusion, the outlying parts of the two networks differ greatly, buses offering vastly better area coverage.

Frequency

Lindenwold Having a single line that generates dense travel, PATCO operates six trains at 10- to 12-min headways in the base period. This schedule requires six train operators. As the volume increases, trains can be lengthened from one to six cars, so that the line's capacity can be increased sixfold with the same personnel. Even the frequent peak-hour service increases labor requirements only to about 15 operators.

NJT Buses NJT buses mostly serve lightly traveled routes, and another driver must be added for each service or 45-space capacity. With the high marginal cost of providing service and its extensive network, NJT cannot provide good frequency.

Comparison Being an intensive line with high trip attraction and having the inherent high and flexible labor productivity of rail modes with a much lower peak-to-base ratio of labor requirement, the PATCO line offers a much higher frequency of service than any NJT bus route, as well as the entire NJT network.

Speed

From the operator's point of view, operating and round-trip speeds are important, because they directly affect the required fleet size and operating cost.

Lindenwold The Lindenwold Line has travel times of 24 to 25 min (varying between off-peak and peak times) on its 14.2-mi (22.8-km) length, bringing the average operating speed to about 35 mph (56.3 km/hr).

NJT Buses These routes have variable speeds, ranging from 10 to 35 mph (16 to 56 km/hr).

Comparison The Lindenwold Line is greatly superior to NJT with respect to speed. Only the longest express bus routes with few stops match the speed of the Lindenwold Line; most of the others have considerably lower operating speeds.

Control and Reliability

Lindenwold The PATCO line's right-of-way is fully controlled, without any contact with other traffic; its stations and trains are under supervision from a central control center by model board and closed-circuit television. Operations are monitored at all times, and information and data on the entire system are available in great detail.

NJT Buses The buses are subject to street traffic delays, and there is no central control for stops or the locations of buses. General information on performance of different routes, ridership, and other statistical data is rather limited.

Comparison The two systems differ in their method of operation, degree of control, and reliability of operations. The Lindenwold Line is greatly superior in its control and the resulting reliability of service. For purposes of analyses of operations, performance, costs, passenger characteristics, and other elements, the Lindenwold Line represents a far superior system.

Costs, Revenues, and Operating Ratios

Lindenwold The Lindenwold Line was constructed in the late 1960s by upgrading an existing Philadelphia-Camden rapid transit line and constructing a 10-mi (16-km) extension to Lindenwold. The cost was $94 million. Subsequent construction of a new station, platform extensions, the purchase of 46 additional cars, and several other upgrades amounted to probably doubling of the initial investment. Detailed statistical data about the Lindenwold Line show that its operating costs have gradually increased from $4.3 million in 1970 to $19.8 million in 1988. Revenues have increased during the same period from $4.2 million in 1970 to $15.4 million in 1988. The operating ratio, 0.78 in 1989, has fluctuated between 0.77 and 0.95, depending on the times of fare increases. Each increase leads to an improvement in the operating ratio, followed by its gradual decrease as inflation progresses.

NJT Buses Because buses use existing streets and highways, no direct infrastructure investment cost can be assigned, with the exception of some station and terminal facilities. As Table 2 shows, operating ratios for different route categories vary between 0.34 and 0.58 and average about 0.54.

Comparison A comparison of the two systems with respect to costs is quite drastic. The Lindenwold Line involved an incomparably higher investment cost, but it shows a persistent ability to cover by passenger revenues a much higher share of its operating costs. Its operating ratios of 0.80 to 0.85 include expenses for the entire PATCO system. Operating ratios for buses are much lower: computed on a direct-cost basis only (i.e., excluding overhead), they amount to only 0.40 to 0.60.

Capacity

Lindenwold Several trains on the Lindenwold Line operate during the peak hours with headways of 2.5 min. This operation represents an offered capacity rate of 21,600 spaces per hour. It is estimated that the line actually carries up to 15,000 passengers per hour.

NJT Buses NJT buses offer a capacity of only 3,000 to 4,000 spaces per hour, but this capacity could be increased if the demand were greater. The capacity of this network is difficult to define physically, because buses use multilane highways and streets. The bottleneck would first appear at major bus stops in downtown Philadelphia.

Comparison The capacity of the Lindenwold Line is distinctly superior to that of NJT.

Side Effects

The most important negative effects on nonusers and the environment for which the operator is responsible are aesthetics, noise, and air pollution.

Lindenwold The sections of line in tunnels and on the bridge have no external impacts; the elevated structure is aesthetically satisfactory, noise levels are low, and air pollution is nonexistent. However, although many underpasses are provided, the line has a certain dividing effect on the area.

NJT Buses Buses in streets are aesthetically satisfactory, but the noise and air pollution caused by them are objectionable, particularly in downtown Philadelphia and Camden.

Comparison NJT buses produce somewhat greater direct negative side effects than does the Lindenwold Line.

Passenger Attraction

The overall ridership attracted by the two systems will be discussed in the section on community requirements. With respect to transit operators, the two systems are quite different in their passenger attraction. NJT buses provide the basic service in and between New Jersey communities, and this includes many local shopping, school, and other trips. The buses attract a certain number of commuters to Philadelphia, but they are not very competitive with the automobile. This is obvious from the low demand for P&R facilities.

The Lindenwold Line, on the other hand, does not provide many local trips because of its long station spacings and limited area coverage. However, it is highly competitive with the automobile and much more capable of diverting trips from highway travel, as shown by the large number of people who access its stations by automobiles. Thus, the PATCO line has a different ridership and must maintain a high quality of service to remain competitive with the automobile.

Community Requirements

Quality of Service

The preceding paragraphs show that the rail and bus systems offer different types of services to the communities they serve.

The Lindenwold Line offers a limited network—a single line—but its service is of the highest quality. Its reliability, speed, comfort, and overall image are excellent. Buses also serve travelers into Philadelphia and Camden, but surveys show that the average income of their commuters is only 74 percent of the income of PATCO line commuters; in addition, the buses serve as the basic carriers of the local population, among whom 75 percent have annual incomes of less than $20,000. Thus, buses also provide a socially important basic transit service.

NJT buses provide an extensive network of services, but with a low frequency and a much weaker image than that of the Lindenwold Line. This difference explains why the Lindenwold Line, with service to only 13 stations, attracts a daily ridership of 39,500 passengers, whereas the 26 bus routes, with a network length of 562 mi (904 km) and approximately 1,500 stops, attract only 27,600 passengers a day, or 43 percent less.

The difference between the two systems is even greater than these numbers show. The NJT bus figures include a large number of short trips within the New Jersey communities. Thus, if commuting into and out of Philadelphia and Camden are separated, where the two systems closely overlap, the Lindenwold Line attracts an even greater share. Also, due to the longer average trip length on the line, its transportation work (in person-miles) is greater than the corresponding transportation work on buses. Unfortunately, exact numbers on this comparison cannot be determined, because the average trip length on the buses is not known.

System Impacts

Due to its strong attraction of automobile drivers, the PATCO line has a major impact on the area it serves. By diverting between 10,000 and 12,000 automobile round-trips per day from highways, the line decreases congestion in the corridor and reduces parking needs in central urban areas, particularly downtown Philadelphia, by this amount. If the line did not exist, some of its riders would not go to Philadelphia at all; however, even those that are induced represent benefits to the riders and the areas to which they go. Thus, the line benefits both users and other travelers and has a substantial impact on activity in the area through increased mobility. Boyce (*8,9*) offers detailed studies of these impacts of the PATCO line.

NJT buses also attract some commuters from automobiles and decrease highway traffic and parking needs in downtown Philadelphia. However, this impact is considerably smaller than the impact of the Lindenwold Line.

Several studies have shown that the Lindenwold Line has had significant impacts on land values, commercial developments, and land uses. NJT has not demonstrated any such impacts, primarily because of its lower level of service than the Lindenwold Line and its lack of infrastructures that have a particularly strong impact on investments and transit system image.

In conclusion, the PATCO rail line has a much greater positive impact on the areas it serves than NJT buses; however, the latter provide an essential social service.

SUMMARY

The results of the parametric analysis and comparison of the two systems are summarized in a simple form in Table 3.

Similarities Between the Two Systems' Roles

The Philadelphia suburbs in southern New Jersey represent an excellent area for the comparison of rail and bus transit modes. Because both PATCO and NJT serve the same general area, there are no significant differences in the external influences that often make this kind of comparison difficult. The type of economy, land-use patterns, population characteristics, incomes, automobile ownership, and, of course, topography and climate, are the same or nearly the same for both modes. Both systems have the same basic role: to serve travel into and out of Philadelphia and Camden. The buses also serve local travel needs among New Jersey communities, which the Lindenwold Line cannot do effectively. Nevertheless, the two systems differ drastically in the quality of service they offer and in their impacts.

Differences

The major service differences that the Lindenwold Line and NJT buses offer are as follows.

1. *Networks*: The two systems represent two extremes in the tradeoff between area coverage and frequency. Lindenwold has a limited area coverage but high service frequency; the buses offer extensive area coverage with low frequency.
2. *Rights-of-way*: The Lindenwold Line has a fully controlled, Category A right-of-way, which allows a high degree of automation in the operation of trains and stations. Buses operate in right-of-way Category C: they use streets and freeways and operate manually in mixed traffic. This difference results in Lindenwold's much higher performance and labor productivity and, consequently, much lower operating costs.
3. *Vehicles and stations*: The ride on PATCO trains is so comfortable that passengers' need to stand is not highly objectionable. Buses offer comfortable seats to every passenger, but the riding comfort and spaciousness are lower than those of rail vehicles.

It is clear from the preceding comparison that the Lindenwold Line offers a service that, although limited to few points, is so distinct and has such a high level of service, convenience, and reliability that it successfully competes with the automobile. The extensive use of P&R and K&R facilities proves that clearly. NJT buses, on the other hand, provide services that are tailored to various types of travel. Individual routes cover many localities and neighborhoods, stop at dozens of locations, operate locally and in express modes on freeways, and make use of typical urban transit buses as well as comfortable suburban buses, without standees. However, their dispersal and low frequency make the buses difficult to recognize and use; their services have a weak image, and therefore they do not compete successfully with automobile travel.

TABLE 3 SUMMARY COMPARISON: LINDENWOLD RAIL LINE AND NJT BUSES

Requirement	Lindenwold	NJT Buses	Higher Rated System
Passenger:			
Availability - Spatial	Fair*	Very good	NJT Buses
Availability - Temporal	Very good	Very poor	LL Rail
Speed/Travel Time	Very good	Fair	LL Rail
Service Reliability	Very good	Good	LL Rail
User Costs	Very good**	Fair	LL Rail
Comfort	Very good	Good	LL Rail
Convenience	Good	Very poor	LL Rail
Safety and Security	Very good	Good	LL Rail
Operator:			
Area Coverage	Good (with auto)	Very good	NJT Buses
Frequency	Very good	Very poor	LL Rail
Speed	Very good	Fair	LL Rail
Control and Reliability	Very good	Fair	LL Rail
Cost: Investment	Poor	Very good	NJT Buses
Operating Ratio	Very good	Fair	LL Rail
Capacity	Very good	Fair	LL Rail
Side Effects	Good	Fair	LL Rail
Passenger Attraction	Very good	Poor	LL Rail
Community:			
Quality of Service	Very good	Fair	LL Rail
System Impact	Good	Fair	LL Rail

Notes: *Including auto and bus feeders.
**Not including cost of automobiles for access.

Performance and Results

The results of these two types of service are drastically different. The rail line, with only 13 stations (7 outlying), attracts 43 percent more passengers than the bus network, which has 26 routes and some 1,500 stopping locations. The Lindenwold Line carries approximately twice as many passengers as NJT into and out of Philadelphia, although the buses attract a larger share of local trips because of their better area coverage.

The PATCO line involved an incomparably higher investment, but it is much more economical to operate. It has low operating costs, and its high level of service enables it to attract more passengers than NJT. As a result, the Lindenwold Line achieves an approximately 44 percent higher operating ratio than NJT, although it charges fares that are between 20 and 30 percent lower.

The direct and indirect impacts of the Lindenwold Line, such as reduction in congestion, increased convenience of travel, attraction of area residents, and impacts on suburban development, are much greater than the impacts of buses. The blending of the buses into the highway network makes their impact much less distinctive and of much lower magnitude. Moreover, the Lindenwold Line has a great potential to support stronger land-use planning and stimulate different urban forms, whereas buses tend merely to follow developments and existing urban form.

CONCLUSIONS: REAL-WORLD EXPERIENCE WITH RAIL AND BUS MODES

This comparison of rail and bus systems that have served the same area for 22 years provides valuable real-world information that should clarify and correct some of the opinions often found in theoretical writings on this topic. A critical review of these writings is presented by Vuchic (*10*).

Basic Features that Attract Passengers

The following conclusions have been drawn about the major features that attract passengers to transit:

- Intensive, high-frequency, high-performance service is vastly superior to extensive, low-quality service, even in low-density suburban areas.
- A distinct line with an infrastructure independent of highway and other traffic provides a permanence and image that strongly attract passengers.
- Flexibility, often claimed as a great advantage of buses, if carried to an extreme is actually detrimental to the passenger-attracting capabilities of a transit system.
- The major service features that attract passengers are high operating speed; high frequency and reliability; and easy,

convenient access by different modes. If these features are provided, certain elements of service, such as the provision of seating, need not be always provided.

- The out-of-pocket cost is more important for passengers than the total cost. They are more sensitive to fares than to such costs as owning an automobile for P&R travel, which may be much higher in the long run than many passengers realize.

Suggested Bus Line Improvements: Service More Similar to Rail

Bus services in southern New Jersey are excessively adjusted to individual user groups; as a result, the routes are complicated and difficult to understand even by regular users. The advantage of buses, which are able to operate on most streets, should not be used to disperse their service and dilute their image. This fact has been proved, for example, in Ottawa, where bus services are much more similar to rail transit service and attract more passengers than most other comparable bus systems.

Possible Rail Line Improvements: Lower Investment for a Larger Network

The PATCO line was designed and built so economically and efficiently that no significant improvements are needed. For transit modes in general, however, certain simplifications of infrastructure and compromises to allow grade crossings (i.e., use of light rail in certain situations) may result in larger networks with better area coverage. In some cases, the downgrading of service through this change is not significant and makes larger rail networks feasible; in others, such as the Lindenwold Line, the quality loss would probably not be offset by the gains from an extended network. The decision on the quality of network, which changes the ratio between investment cost and level of performance, must therefore be based on local conditions.

Correcting Misconceptions about Rail Transit

Various theoretical studies critical of rail transit as a mode have been given considerable publicity in the United States and Great Britain, regardless of their quality and accuracy. Even some government officials and reputable organizations, such as The Urban Land Institute, have made statements to the effect that buses are not only cheaper, but can offer services superior to rail because of their flexibility and ability to serve large, low-density areas (*11*). Rail transit, it is admitted, may be economical and efficient on the existing lines in older cities, but it is said to be expensive and ineffectual for low-density suburbs.

This paper, as well as many earlier studies (*1,3,4,7*), clearly shows that these theoretical studies that make a general criticism of rail transit modes are incorrect. Different modes have different domains of optimal applications. Statements that either rail or bus is better than the other for most applications are inherently wrong. Actually, the two modes are complementary: rail lines usually depend on bus feeders.

In reality, rail transit offers superior service to that of buses in dispersed networks, and it is much more attractive to automobile drivers. With the downgrading of busways into HOV lanes in many U.S. cities, the competitiveness of buses with automobiles has been further eroded.

A second important conclusion is that the large investment rail transit requires is probably the only significant negative aspect of rail transit. If the projected ridership and impacts justify the investment, rail transit can have higher operating ratios than those typical for either older rail or modern bus systems.

Consequently, rail transit can in many cases represent the most effective and, in the long run, most economical transit mode for both high-density cities and low-density suburbs. Its effectiveness consists of strong attraction of automobile passengers, a decrease of traffic and parking pressures in cities, and positive influences on urban form and environment. This conclusion explains why most of the recent construction of rail transit has been taking place in automobile-oriented cities (e.g., Los Angeles, San Diego, Edmonton, Sacramento, San Jose, Calgary, Portland, and San Francisco), which have recognized that highways alone cannot satisfy their needs.

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Net Costs of Peak and Offpeak Transit Trips Taken Nationwide by Mode

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Estimates are made of the net costs of trips taken during peak and offpeak periods on bus, subway, and commuter rail systems in the United States, both separately and averaged over all three of these transit modes. Net costs are defined as the sum of annual operating and maintenance expenses and annualized capital costs minus passenger revenues. Various cost and revenue allocation factors and related assumptions were used to estimate net costs using actual data for transit systems providing bus, subway, and commuter rail service. The results indicate that transit trips taken during peak periods, expressed on either a per-trip or a per-passenger-mile basis, have consistently higher net costs than trips taken during offpeak periods. Nationwide, the average net cost for a transit trip taken in the peak period during 1983 is estimated at $1.74, compared with an estimate of $1.20 for a trip taken in the offpeak. This difference occurs primarily because a relatively higher proportion of transit capital expenses is attributable to providing for the peak periods. Although passenger revenues are proportionally high in the peak, they are not of sufficient magnitude to result in lower net costs during this period. When costs and revenues are expressed on a per-passenger-mile basis, which normalizes for trips of different lengths, the disparity in net costs by mode and time of day is reduced.

Estimates are made of the net costs of peak and offpeak trips that are taken on all bus, subway, and commuter rail systems in the United States (*1*). Net costs (i.e., deficits) are defined as the sum of annual operating and maintenance expenses and annualized capital costs, minus passenger revenues received for trips taken during the peak and offpeak periods. The peak is defined as the five hours from 7:00 to 9:00 a.m. and from 4:00 to 7:00 p.m.

Average net costs per trip and per passenger-mile for both the peak and offpeak periods are estimated on the basis of data representative of all bus, subway, and commuter rail systems in the United States. This disaggregate information is useful in understanding how net costs vary by mode and time of day. However, as McGillivray et al. (*2*) note, this type of analysis is most helpful in evaluating questions pertaining to pricing policy rather than many other short-range planning applications. The latter concerns would best be addressed through an analysis of the marginal costs and revenues that would likely result from particular service changes.

Earlier cost allocation studies generally fall into one of four categories. The first, which contains the largest number of studies, is the route-level cost allocation study. These studies are typically performed for an individual or single transit agency and are intended to examine how costs vary by route and in some instances by time of day. Except for a study of the New York subway system (*3*), the vast majority of these route-level studies focus only on bus systems. The second type of study examines the issue of scale economies in the transit industry, again, usually for bus systems. The third type of study is concerned with the issue of equity in transit finance, which is usually analyzed by examining subsidies provided to users of different urban transit modes. The fourth type of study is aimed at undertaking a comparative analysis of the full costs (i.e., both supplier and user travel costs) of trips made by alternative modes. In general, all of the cost allocation studies included in these four categories have some elements (in varying degrees) in common with the present study; however, no known single study has made estimates of the net costs (as defined) of providing transit service in the United States by mode and time of day.

The analysis of transit deficits presented here builds on a Charles River Associates (CRA) study (*4*) performed for UMTA, which examined the distribution of federal operating subsidies by income group. The analysis of net operating and maintenance costs by time of day were extended to include a measure of annualized capital costs for all bus, subway, and commuter rail trips taken nationwide (*1*).

OVERVIEW OF THE NATIONWIDE COST AND PASSENGER REVENUE ALLOCATION METHODOLOGY

Allocation of Operating and Maintenance Expenses

Operating and maintenance costs for bus and subway systems were assigned to the peak or offpeak period using information obtained from UMTA's *1983 Section 15 Annual Report* (*5*) to be consistent with the earlier CRA study (*4*). The basic methodology for allocating operating and maintenance costs followed the general logic used in the route-level, accounting-based studies. Expenses in each major cost category were divided between the peak and the base period according to the amount of service supplied (e.g., vehicle-hours) and the relative productivity associated with each period. Those particular cost categories that typically vary as a function of the number of passenger-miles of service produced were then expressed on a per-passenger-mile basis. The cost of an individual trip was computed as the product of the length of the trip in miles multiplied by the appropriate (per passenger-mile) cost coefficients for the time of day during which the trip occurred, plus any per-trip fixed expenses. In general,

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the following procedure was used in making the necessary calculations:

1. Separate transit operating and maintenance expenses into accounting cost categories, by mode;
2. Assign a fraction of each cost category to the peak and base periods using various allocation measures, and determine which costs vary with the number of passenger-miles of service produced; and
3. Formulate mathematical relationships based on Step 2 and estimate peak and offpeak operating costs by mode based on observed trip length distributions by time of day.

Each of these steps is briefly described in the following paragraphs.

Step 1: Classify expenses by category and mode

The UMTA *1983 Section 15 Annual Report* (*5*) contains a breakdown of transit operating expenses by mode and by function. The functions to which costs are attributed include vehicle operations, vehicle maintenance, nonvehicle maintenance, and general administration. Vehicle operations account for the largest category of costs, because it includes expenses related to transportation labor. Because of various work rules, labor expenses per unit of service supplied are higher in the peak than in the base period and therefore need to be allocated separately. For single-mode motor bus systems, labor expenses represent about 80 percent of the costs incurred in this category (*5*).

Step 2: Determine how costs vary by peak and offpeak periods

For bus and subway modes, the procedures used for allocating operating costs by functional categories are described in the following sections (but in reverse order for presentation purposes).

General administration expenses are assigned to the peak and offpeak periods on a per-trip basis. This method of assignment was chosen because the extent of administrative functions, such as marketing, schedule printing, and service planning, are determined primarily by the number of passengers served rather than by the number of vehicle-miles produced. Furthermore, it is unlikely that these expenses, expressed on a per-trip basis, are affected by the time period in which the trip occurs. Thus, each trip is credited with a fixed expense for these overhead functions.

Total vehicle maintenance expenses first are allocated to peak and offpeak on the basis of vehicle-hours of service. Vehicle-hours are used to allocate this cost category between periods, because maintenance expenses result from the duration of actual vehicle use. This method of assignment assumes that each vehicle-hour of service results in the same maintenance expense, regardless of the time during which the vehicle is in operation.

Nonvehicle maintenance expenses include the costs of maintaining stations, rights-of-way, and other structures. This category of costs is allocated on the basis of relative passenger-miles in each period. This allocation method attempts to account for the intensity of facility use in each period. Within each period, nonvehicle maintenance expenses are assigned to a given trip in proportion to the length of trip.

Nonlabor vehicle operations expenses are divided between time periods on a vehicle-hour basis. Vehicle-hours are used because this category is dominated by fuel and tire expenses, which vary with the number of vehicle-hours of service produced. There is some justification for assigning a higher per-hour cost to the peak period on the grounds that average vehicle speeds are lower, and hence fuel consumption is higher, in the congested peak hours. However, to an unknown extent, the effects of congestion on average vehicle speeds are offset by the larger proportion of express and special-service runs in the peak. These services typically operate over limited-access roadways for some portion of the route, bringing up the average vehicle speeds for peak-period services. In the absence of solid empirical evidence concerning relative vehicle productivity, nonlabor vehicle operating expenses are assigned on a constant cost per vehicle-hour.

For *vehicle operations labor* expenses, it is well known that unit labor costs are higher in the peak period than in the base because of various work rules and labor conditions intrinsic to the peak. Previous studies of allocating costs between time periods have focused on relative labor productivity, defined as the ratio of pay hours per vehicle-hour in the peak to pay hours per vehicle-hour in the base. This statistic captures the effect of higher hourly wages for peak-period service and productivity differentials caused by split shifts, 8-hr minimum shifts, and other rules.

On the basis of a review of prior studies (*6–11*), an average of 1.20 was determined as an estimate of relative labor productivity for bus systems. [Mohring (*12*) and Boyd et al. (*13*) make use of a higher relative labor productivity figure, but one that is not based on empirical data.] No studies focusing on equivalent subway labor productivity factors were found. However, in a recent study of the New York City subway system, Hirschman (*14*) examined the way certain operating and maintenance cost items varied between peak and offpeak periods. His analysis of operating costs per train-hour—a significant portion of which includes labor (crew) costs—indicates that relative labor productivities for subway systems are likely to exceed 1.20, even after adjusting for the shorter 4-hr peak period assumed in his analysis. (If peak labor productivity factors for subway systems were greater than 1.20, relatively higher net costs in peak periods than shown here would result.)

Following the logic implicit in the route-level cost allocation studies, transportation labor costs for bus and subway systems are apportioned between peak and offpeak periods on the basis of vehicle-hours of service supplied in each period, with higher labor costs per vehicle-hour attributed to the peak. Commuter rail operating expenses by function are not available in the *1983 Section 15 Annual Report* (*5*). Consequently, each commuter rail trip is assigned the same (operating) cost per passenger-mile, regardless of the time period in which the trip was taken. To the extent that peak-period costs are higher per passenger-mile than base-period costs, this commuter rail cost assumption will underestimate the peak-period deficits on commuter rail. Although potentially significant for the commuter rail segment, averaged over all transit trips nationwide, this underestimate is likely to be small, because only 5 percent of all transit trips are made using commuter rail.

Step 3: Formulate Cost Equations and Estimate Peak and Offpeak Operating Costs

The methods described for allocating individual line items by function were incorporated into various equations that were subsequently used to estimate the cost of specific trips by time of day. The equations are described in more detail in the full CRA report (*1*).

Allocation of Annualized Capital Expenses

General Overview

Earlier cost allocation studies have presented differing points of view on how capital costs for transit systems should be allocated between peak and offpeak periods. Furthermore, even the range of capital costs considered is not addressed consistently. For example, some studies (typically those for bus systems) consider capital costs, but only for vehicles—presumably because vehicles represent the largest share of capital expenditures for bus operations. It is not uncommon to find instances in which capital expenses for bus garages and maintenance facilities are ignored. In other instances, particularly for rail transit systems, capital costs are discussed in terms of vehicles, rights-of-way, and structures (e.g., bridges and tunnels) that, because of varying useful lives, have different impacts on annualized capital costs. With respect to vehicles, some studies suggest that useful life is based on age, whereas others indicate that miles traveled, or some combination of the two, is the most important factor in replacement decisions.

A more fundamental issue that is sometimes advanced concerns whether a particular transit mode would exist at all if it were not for the singular need to provide peak-hour service. As Meyer et al. observe (*15*), "If the basis of design and justification of downtown-oriented systems is the rush-hour flow, as it usually seems to be, then it can be argued that the full costs of providing the capacity needed for that service should be charged to rush-hour travelers." The concept of charging peak users the full capital costs follows earlier studies in electricity utility pricing (*16*). Others remain unconvinced of this particular allocation concept (*17*). Coase (*18*) goes further by stating that ". . . the allocation of joint or common costs between products or services for the purpose of determining prices is without meaning." In a similar vein, McGillivray et al. (*2*) caution that any approach to capital cost allocation ". . . usually stumbles over the intractable problem of allocating the common costs . . . and hence . . . is quite sensitive to essentially arbitrary assumptions." As a middle ground to the problem of allocating joint costs between two user groups, Loehman and Whinston (*19*) propose that joint costs be computed using the different allocation methodologies possible and that a weighted average of these costs be computed.

Previous Practice in Transit Cost Allocation

Earlier studies that have considered the issues pertaining to allocating transit capital costs between peak and offpeak users can be separated into two groups: (a) those advocating that all capital costs be assigned to the peak and (b) those advocating that costs be shared in some fashion between peak and offpeak users. The studies in the first group generally base their arguments on the principle that peak demands determine the level of capital required and therefore these users should be assessed the full capital costs. Meyer et al. (*15*) not only advance this position but go a step further by indicating that all capital costs be allocated to users traveling in the peak direction. The concept of allocating annualized capital costs to peak users has been followed by Mohring (*12*), Reilly (*11*), Cherwony and Mundle (*10*), and in bus studies conducted in the early 1970s and reported by Taylor (*20*), Parker and Blackledge (*21*), and McClenahan and Kaye (*22*).

In a study of the full costs of urban transport, Keeler et al. (*23*) favor the concept of allocating all capital costs to the peak. However, as part of this larger study, Merewitz (*24*) recognizes that some may find this allocation decision to be arbitrary and therefore proposes to share capital expenditures between the peak and the offpeak, using the results of a full-cost study by Boyd et al. (*13*). The latter study is an early example of the second group of transit cost allocation studies that advocate sharing capital costs according to relative usage. Other studies that fall into this group include the works of Levinson (*25*), Cervero et al. (*7*), Lee (*26*), and Kerin (*27*).

Recommended Approach

Given that there is no unambiguous way to assign transit capital costs associated with vehicles and infrastructure by time of day, a preferable strategy would be to select a methodology that falls between the extremes of the two approaches discussed in the preceding section. This has been accomplished by assuming that 85 percent of the annualized capital cost for bus, subway, and commuter rail vehicles can be allocated to the peak period, following previous studies (*7,13*). It is likely that the size of most rail fixed facilities has been geared to meet peak demands, suggesting that 100 percent of the capital infrastructure costs be assigned to the peak. The other extreme suggests that about 70 percent of right-of-way and structure capital costs for rail rapid-transit (or approximately 80 percent for the more peaked commuter rail systems) be allocated to the peak period (*7*). Because, on average, this process would represent about 85 percent of fixed capital costs, 85 percent is used to represent the peak capital expense factor for subway and commuter rail.

A stronger case can be made that bus service, which is less peaked to begin with, would likely be offered without the presence of a morning and evening peak. Thus, a proportionately larger share of the fixed facilities for bus systems should be allocated to the offpeak. Using the Boyd et al. methodology (*13*), but assuming that only 46 percent of the bus riders (based on 1983–1984 Nationwide Personal Transportation Study data) are carried during the peak, results in a peak allocation factor of 56 percent for bus way and structure items. However, given that there are few, if any, right-of-way costs for bus systems and that vehicle expenses represent the largest share of capital expenditures, an approximate weighted average between vehicle and right-of-way of 80 percent has been estimated for allocating bus capital expenses to the peak period.

Allocation of Passenger Revenues

Passenger revenues for peak and offpeak periods were computed on the basis of the product of the number of passenger trips taken during these two time periods and average passenger fares paid by users of bus, subway, and commuter rail systems across the United States. Average fares per trip (77 and 60 cents for subway and bus systems, respectively) were calculated for single-mode systems from data in the UMTA *1983 Section 15 Annual Report* (*5*), supplemented by additional information obtained directly from transit systems operating more than one mode. Finally, fares on commuter rail systems were assumed to be proportional to trip length, with passenger revenues for 1983 obtained from the American Public Transit Association (APTA) (*28*).

ESTIMATION OF NET COSTS BY MODE FOR PEAK AND OFFPEAK TRANSIT TRIPS

The following sections summarize the results obtained in estimating operating and maintenance costs, capital costs, passenger revenues, and net costs by mode and time of day for trips taken on all bus, subway, and commuter rail systems in the United States.

Allocation of Operating and Maintenance Expenses

Operating and maintenance expenses for bus, subway, and commuter rail systems nationwide were allocated to peak and offpeak periods on the basis of actual data from UMTA (*5*), using the methods described previously. The resulting peak and offpeak annual expenses by mode are summarized in Table 1. Overall, the results tend to reflect the relative differences in the peaking characteristics of each mode; commuter rail, for example, had the highest percentage of operating and maintenance costs occurring in the peak.

Allocation of Annualized Capital Expenses

According to UMTA (*5*), $2,787 million was expended in 1983 for capital projects by nearly all transit systems in the United States from all sources of public capital assistance. In addition, in FY 1983, about $3.2 billion in UMTA capital grants were obligated, but not necessarily expended (*29*). The actual amounts expended are difficult to determine from this figure, because other sources are used to match UMTA grants, which would tend to result in a larger number. This factor is offset, however, by the fact that obligations are expended over more than 1 year.

Neither UMTA report (*5,29*) disaggregates capital expenses by the three major transit modes included here. However, APTA (*28*) presents information on federal capital grant approvals by transit mode. Averaged over the period 1965 to 1983, federal capital grants for bus, subway, and commuter rail systems were 32.2, 54.2, and 13.6 percent, respectively. Thus, these averages over a relatively long period (which smooth out year-to-year variations) can be used to allocate by mode the total capital expenditures that were made in 1983, assuming that the modal distribution for federal allocations reasonably reflect that for total allocations. The resultant capital expenditures by mode and time period are presented in Table 2.

Allocation of Passenger Revenues

Following the allocation methods described in preceding sections and using data sources consistent with the estimation of operating and maintenance expenses by time of day, Table 3 presents the ridership and passenger revenue statistics by time period for each transit mode. As expected, those transit systems with a higher concentration of riders in the peak (e.g., commuter rail) have a correspondingly higher percentage of passenger revenue occurring in the peak.

Net Cost of Peak and Offpeak Transit Service

The net cost of peak and offpeak trips taken on transit systems nationwide can be calculated as the sum of annual operating and maintenance expenses (Table 1) plus annualized capital costs (Table 2) minus passenger revenues (Table 3). A summary of these calculations is presented in Table 4.

TABLE 1 NATIONAL OPERATING AND MAINTENANCE EXPENSES FOR PEAK AND OFFPEAK PERIODS BY TRANSIT MODE FOR 1983 (MILLIONS)

Mode	Peak	Off-Peak	Total
Bus	$ 2,337	$ 2,898	$ 5,235
Subway	1,258	984	2,242
Commuter Rail	907	271	1,178
Total	$ 4,502	$ 4,153	$ 8,655

SOURCE: 1983 Section 15 Report microcomputer diskette and calculations by Charles River Associates.

TABLE 2 NATIONAL CAPITAL EXPENSES FOR PEAK AND OFFPEAK PERIODS BY TRANSIT MODE FOR 1983

Mode	Percent of Capital Funds	Percent Allocated To Peak	Capital Expenses (millions) Peak	Off-Peak	Total
Bus	32.2%	80%	$ 718	$ 179	$ 897
Subway	54.2	85	1,284	227	1,511
Commuter Rail	13.6	85	322	57	379
	100.0%		$2,324	$ 463	$2,787

SOURCE: American Public Transit Association, *1988 Transit Fact Book*, Washington, D.C., 1988; Urban Mass Transportation Administration, *National Urban Mass Transportation Statistics, 1983, Section 15 Annual Report*, December, 1984; and calculations by Charles River Associates.

TABLE 3 NATIONAL RIDERSHIP AND PASSENGER REVENUE FOR PEAK AND OFFPEAK PERIODS BY TRANSIT MODE FOR 1983

	Linked Trips (millions)			Passenger-Miles (millions)			Passenger Revenue ($ millions)		
Mode	Peak	Offpeak	Total	Peak	Offpeak	Total	Peak	Offpeak	Total
Bus	1,587	1,871	3,458	10,093	10,822	20,915	951	1,121	2,072
Subway	925	520	1,445	11,267	5,606	16,873	712	400	1,112
Commuter rail	194	68	262	4,130	1,227	5,357	467	139	606
Total	2,706	2,459	5,165	25,490	17,655	43,145	2,130	1,660	3,790

Source: Tabulations from the 1983–1984 Nationwide Personal Transportation Study; *1985 Transit Fact Book*, American Public Transit Association, 1985; 1983 telephone survey of New York City transit riders, *Transit Pass Marketing Study*, Charles River Associates, Sept. 1983; and *Allocation of Federal Transit Operating Subsidies to Riders by Income Group*, Charles River Associates, Draft Final Report prepared for UMTA, March 1986.

As presented in Table 4, the peak period has the highest net costs for each of the three transit modes. On a per-trip basis, however, the net cost nationwide for a peak trip averaged over all three transit modes in 1983 was $1.74, compared to an estimate of $1.20 for an offpeak trip. On a relative basis, the largest difference in net costs between a peak trip and an offpeak trip occurs in the case of commuter rail. In this instance, the net cost per trip was $3.93 in the peak versus $2.78 in the offpeak.

When expressed on a per-passenger-mile basis, the differences in net costs between the peak and offpeak periods are not as large, although deficits for a peak trip are still greater than those in the offpeak. Again, this is truer for commuter rail than for either bus or subway systems.

CONCLUSIONS

Estimates of the net costs of trips taken on bus, subway, and commuter rail systems in the United States during peak and offpeak periods are provided. Net costs are defined to include capital costs as well as more traditional estimates of operating and maintenance expenses minus passenger revenues. A variety of allocation factors have been used in conjunction with actual transit expenditures to derive the estimates presented.

On the basis of the data and assumptions used, the net costs of transit trips taken in the peak are higher than for trips taken in the offpeak, although the differences are not as large when net costs are expressed on a per-passenger-mile basis. These results suggest that further consideration be given to the adoption of peak-period surcharges, or the use of distance-based fares, because average trip lengths are typically longer in the peak.

As indicated earlier, the numerical results may change if alternative assumptions on certain of the allocation factors are adopted. In addition, while useful on a nationwide analysis, site-specific conditions, or the use of a marginal cost analysis, may lead to different conclusions for any particular transit property.

TABLE 4 NET COSTS OF PEAK AND OFFPEAK TRANSIT TRIPS IN THE UNITED STATES BY TRANSIT MODE FOR 1983

	Bus			Subway			Commuter Rail			Total		
Item	Peak	Off-Peak	Total	Peak	Off-Peak	Total	Peak	Off-Peak	Total	Peak	Off-Peak	Total
Operating and Maintenance Cost (millions)	$2,337	$2,898	$5,235	$1,258	$984	$2,242	$907	$271	$1,178	$4,502	$4,153	$8,655
Capital Cost (millions)	718	179	897	1,284	277	1,511	322	57	379	2,324	463	2,787
Passenger Revenue (millions)	(951)	(1,121)	(2,072)	(712)	(400)	(1,112)	(467)	(139)	(606)	(2,130)	(1,660)	(3,790)
Net Costs:												
Total (millions)	$2,104	$1,956	$4,060	$1,830	$811	$2,641	$762	$189	$951	$4,696	$2,956	$7,652
Per Trip	$1.33	$1.05	$1.17	$1.98	$1.56	$1.83	$3.93	$2.78	$3.63	$1.74	$1.20	$1.48
Per Passenger Mile	$0.208	$0.181	$0.194	$0.162	$0.145	$0.157	$0.185	$0.154	$0.178	$0.184	$0.167	$0.177

SOURCE: Tables 1, 2, 3.

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The Right-of-Way Agreement: Nine-Jurisdiction Plan for Tomorrow

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In January 1988, representatives of nine very diverse public jurisdictions met to sign an agreement to preserve rights-of-way for a high-capacity transit system that was, at best, a distant dream. One year later, that agreement has produced a series of accomplishments that have moved creation of high-capacity transit closer to the realm of reality. The agreement has produced tangible products for Snohomish County, cities, the public utility district, transit agencies, the Washington State Department of Transportation, and the Puget Sound Council of Governments, which were the agreement's creators and signators. These products include a series of preplanning studies, a process for integrating work programs of related projects, and a review mechanism for projects with potential impacts on the right-of-way. There are also less tangible products. First, the elected officials and staff people who were involved have a strong sense of accomplishment. Second, the agreement may serve as a model for neighboring jurisdictions. Third, the collaborative process that emerged during the design of the agreement has been used since then for other difficult issues. The steps that led to the signing of the agreement and the first year's experience in using the agreement may be instructive to other jurisdictions considering visionary projects.

Rapid growth, mounting congestion, and a sense that doing business as usual will not solve the mobility problems facing an urbanizing county led county officials to join their counterparts in the region to discuss high-capacity (express bus and rail transit) solutions. After several years of planning, the need to preserve rights-of-way for future use became a mounting priority.

Snohomish County, Washington, lies north of King County, which includes Seattle. Southwest Snohomish County, which lies along the I-5 corridor and is rapidly urbanizing, is bounded at its northern edge by Everett, the county seat and site of the future Navy Homeport. Scattered through the area are a number of substantial employers, including Boeing's largest commercial aircraft plant, and the Technology Corridor dotted with high-technology complexes. The balance of the county is lower density suburban and rural.

POPULATION AND EMPLOYMENT

As presented in Table 1, Snohomish County is no longer a sleepy suburban area providing bedrooms for Seattle and King County. The Puget Sound Council of Governments (PSCOG) projects phenomenal growth for the whole central Puget Sound area and particularly Snohomish County.

Southwest Snohomish County's growth promises to be even more dramatic. In 1980, Southwest Snohomish County had 63.0 percent of the county's population and 72.9 percent of its jobs. By the year 2020, the southwestern portion of the county is projected to double its population and increase its employment base by a factor of 2½ (*1*).

Travel Demand

The I-5 corridor from the Snohomish County line to Seattle is the most heavily traveled corridor in Washington state. In 1980, 36 percent of Snohomish County's residents and 50 percent of Southwest County's workers commuted to (or through) King County. Almost all of these trips used, in some part, the I-5 corridor (*2*). Much of this commuter demand, projected to double by 2020, will have to be carried on I-5 because the only existing alternative, I-405, bypasses Seattle and no alternative routes have been developed or are planned.

According to the North Corridor Extension (NEXT) Project estimates, by 2000, King County-bound transit use rates from Southwest Snohomish County will double the mid-1980s' rate, which ranged from 5 to 15 percent. By 2020, transit use is projected to increase substantially as land use densities enhance access to transit and massive congestion drives people away from their automobiles.

High-Capacity Transit Planning: 1983–1986

The combination of population and employment growth and projected travel demand in the I-5 corridor led King and Snohomish County officials to begin a series of high-capacity transit studies in the early 1980s. Three major studies formed the basis for the right-of-way preservation program.

1. The first project, conducted by PSCOG and Metro Transit, covered I-5 north of Seattle to just north of the Snohomish County line. The North Corridor Project determined that rail or high-speed bus was feasible in the North Corridor.

TABLE 1 SNOHOMISH COUNTY, WASHINGTON, POPULATION AND EMPLOYMENT FORECASTS

Forecast Total	1980	1990	2000	2020
Population	337,720	429,016	555,854	788,346
Households	120,699	164,285	220,288	334,693
Employment	116,582	153,819	205,444	297,245

SOURCE: PSCOG, June 1988

SNO-TRAN, 5800 198th St., S.W., Ste. A-2, Lynnwood, Wash. 98036.

2. Based on that study, the Snohomish County Transportation Authority (SNO–TRAN) undertook an analysis (the NEXT Project) of high-capacity transit feasibility in Southwestern Snohomish County. This project stretched from the Snohomish County line to just north of Everett.

3. In response to expressions of interest from other parts of King County, Metro and PSCOG undertook the Multi-Corridor Project, a broader based high-capacity transit study, which added the corridors east and south of Seattle to the work done to the north. A fourth study, the TAC–SEA Project, explored extensions of the high-capacity system south to Tacoma.

In January 1986, the Board of SNO–TRAN found that rail transit would be feasible in the Southwest Snohomish County portion of the I-5 corridor and instructed the NEXT Project to continue work toward the creation of a rail system. Priority was given to right-of-way preservation because reality indicated that any high-capacity system, specially rail, would be many years in the future.

This reality was borne out by subsequent actions of the Multi-Corridor Project. In June 1986, the Multi-Corridor Project was held off until some time between 1993 and 1995, when a variety of indicators would structure the next steps in high-capacity transit (rail) planning. Because King County would contain 90 percent of some 110 mi of a regional rail transit system, the action of the Multi-Corridor Project put all rail planning in the region effectively in limbo.

SNO–TRAN's Decision to Move Forward

Despite the decision in King County, SNO–TRAN officials adopted an interim work program, designed to carry forward high-capacity planning until the 1993–1995 reconsideration of rail system development. The interim work program was designed to address unanswered questions and solve problems in Snohomish County that local officials felt could not be held off. Right-of-way preservation topped the list.

Three issues emerged immediately. Rights-of-way could not be preserved because (a) regional decisions effectively eliminated the project from the short-term calendar; (b) no one knew if the project ever would come into Snohomish County; and (c) SNO–TRAN, the countywide public transportation planning agency, only had a staff of three and no assets that could be used to secure land.

The one asset that SNO–TRAN and the NEXT Project had was cooperation. The NEXT Project had been created as a joint endeavor of PSCOG, SNO–TRAN, and the county's two transit operators. A 13-member policy committee made up of elected officials, representing all the jurisdictions in the NEXT study area, provided overall policy coordination. A technical advisory committee (TAC) of senior planning and public works personnel from each of the study area jurisdictions supported the project staff and the policy committee.

In addition to a structure that brought in all the affected parties, the NEXT Project actively sought consensus throughout its first phase. When SNO–TRAN adopted the concept of rail, that action was taken to each of the jurisdictions in the study area for ratification. The *NEXT Newsletter* was sent regularly to public officials, community leaders, and agency personnel to keep information moving throughout the study area and beyond.

THE AGREEMENT

As early as December 1985, development of a right-of-way preservation strategy had become a major topic for NEXT Project participants. Before the June 1986 Multi-Corridor Project action to hold off rail planning, it had been assumed that right-of-way acquisition might begin as early as 1990, following the official designation of the high-capacity corridor.

The Genesis of the Right-of-Way Agreement

Following the Multi-Corridor Project action, the NEXT Project Team convened a special meeting of the TAC to consider what elements of the NEXT Project work program could be rescued. The TAC recommended an intergovernmental agreement that would hold right-of-way until a rail system construction program could be approved for the region. An 18-month development program began that resulted in a nine-jurisdiction agreement to preserve options for high-capacity transit rights-of-way in the I-5 corridor.

The Battle to Agree

In 6 months, the TAC decided what the agreement would contain and in another 4 months a first draft was created. By the time it was transmitted to the attorneys of the nine jurisdictions in May 1987, the agreement had gone through three major revisions. The attorneys took another 4 months to review the document; by the time their last review was completed, six more versions had been developed. By the time the nine agencies signed the agreement in January 1988, the agreement had undergone 11 formal revisions.

What were the issues that resulted in so many changes over the 18-month design period of the agreement? Some concerned overall policy relative to rail versus other high-capacity transit modes. In a largely suburban county, the logic of fixed-route rail versus more flexibly routed bus transit was a major concern. Other issues were motivated by fear that the process was moving too fast and might jeopardize later efforts including those to secure federal funding. Specifically, concerns were voiced about UMTA's prohibition on prematurely selecting alignments and sites before completing UMTA's full alternatives analysis process. At the time these debates were going on, the use of federal funds for the high-capacity system was considered definite. Concerns about local autonomy and land use planning processes headed many agendas. Local control of land use planning is a binding principle in Washington state and one that was jealously guarded by each of the jurisdictions' representatives. Adding complexity to already complex planning and project review procedures raised hackles on virtually all the participants. Legal issues such as binding of future decision makers and interfering with the state's environmental protection laws dominated much of the attorneys' discussions.

A substantive issue that could have killed the agreement emerged after months of negotiation. Several of the jurisdictions raised fears that the agreement would undercut or supersede comprehensive plans, transportation planning policies, and standing procedures for environmental reviews. For example, from Snohomish County's perspective this agreement applied to an area greater than any covered by any of its plans. (The county does not have a single, comprehensive plan.) The implications of this issue alone suggested months of debate. As a result of a session with the jurisdictions' attorneys, it was decided that this agreement would be classed with those agreements (favored by policy makers) that set direction but do not have force of law. This agreement then would be considered an informal agreement rather than a legally binding formal contract. Although this arrangement appeared inadequate to those who felt right-of-way preservation called for stronger actions, the majority knew that the only way the agreement would be approved was to make it voluntary.

The extent to which the participants exerted efforts to make the agreement work was gratifying. For example, the nine attorneys agreed to send a set of delegates to hash out the last necessary legal language changes. The attorneys, along with the TAC members, then acted as advocates for the agreement when the final draft went to each of the nine jurisdictions for adoption. Without their support, the entire effort would have floundered.

The Product

In reviewing the 11 versions of the agreement, it is hard to discern the major changes that occurred during its construction. Many of the changes were small—wording changes to please one jurisdiction or another. Other changes were substantive and reflected serious analyses of issues related to preserving land without solid authority to do so.

The final agreement contains four major elements:

1. Statements of concurrence that high-capacity transit can benefit Snohomish County residents and businesses and that right-of-way for the high-capacity transit system and its associated facilities should be preserved through policy and planning actions consistent with other governmental considerations.
2. Statements of roles and responsibilities for each of the nine signator jurisdictions.
3. Descriptions of a right-of-way reservation program that includes a project review process, authorizes special studies, and encourages public information efforts about right-of-way reservation. The agreement establishes budgetary procedures to support the reservation program.
4. Maps of the right-of-way with proposed station areas and park-and-ride lot locations. Right-of-way is defined in the agreement to include both the land for tracks or busways and land for all related facilities such as stations, parking, and maintenance yards.

Two of these elements have proved to be most significant in the year since the agreement was signed: the roles and responsibilities, and the reservation program.

Roles and Responsibilities

According to the agreement, "the parties . . . have set out the following roles and responsibilities." Six pages assigned functions to each of the nine signator agencies. Briefly, these roles and responsibilities are as follows.

SNO-TRAN will manage the right-of-way reservation program, administer funds, coordinate program-related work, and serve as liaison with the parties.

Snohomish County and the cities of Everett, Lynnwood, and Mountlake Terrace will be responsible for local land use planning and decision making along the right-of-way. They will include the I-5 corridor as the high-capacity transit system corridor in their comprehensive and transportation planning considerations. In addition, they will study land use and transportation impacts in the vicinities of the proposed stations and (if consistent with other governmental considerations) adopt policies encouraging future developments that are compatible with or support the high-capacity transit system. They will participate in the right-of-way reservation review process.

Community Transit and Everett Transit, the two transit operators, will (a) designate the I-5 corridor in their transit plans as the future high-capacity transit route; (b) evaluate future bus service requirements and begin planning transitional service and facilities that can be converted to or complement the high-capacity transit system; and (c) participate in the right-of-way process.

The Washington State Department of Transportation (DOT), with jurisdiction over the I-5 corridor, will (a) cooperate with local jurisdictions in the development of the high-capacity transit system; (b) participate in the right-of-way review process; and (c) "review for consistency with the high capacity system all decisions affecting the I-5 right-of-way . . . ."

The public utility district (PUD), responsible for the old interurban rail right-of-way parallel to I-5 and a key alternative in certain areas, will "recognize and consider" the interurban right-of-way for high-capacity transit and participate in the right-of-way review process.

PSCOG will "adopt and maintain a regional high capacity transit plan component as part of the Regional Transportation Plan" and will manage the right-of-way review process.

THE RIGHT-OF-WAY RESERVATION PROGRAM

The Right-of-Way Reservation Program element of the agreement has three parts, two of which have been particularly successful during the agreement's first year.

The Right-of-Way Review Process

The right-of-way review process took many additional months to define once the agreement was signed. When the agreement was being drafted, there was consensus that the review process should be referenced only generally so that the particulars of the process could change over time, as an understanding of how it worked was gained and as conditions changed. Under no circumstances was the process of amending the agreement every time the review process needed revision considered desirable.

The review process design eventually was fitted into the existing State Environmental Protection Act (SEPA) check list review process. This was done to (a) avoid creating another review process; (b) fit this review into existing review agency staff assignments; (c) fit this review into a formal processing timetable; and (d) reach a spectrum of agencies that might have an interest in the review. A universal priority was keeping the process simple and not adding to the work loads or time lines that review agencies must follow.

Once these decisions were made, PSCOG developed a review form that was discussed thoroughly and revised several times before the TAC adopted it.

Only after the review process had been formalized was the following set of unanticipated loopholes in the program identified:

1. The review process starts simultaneously with the SEPA review stage, which is far down the project development process. In some cases, earlier notification would be more beneficial because the project could be altered before plans solidified.
2. Major interjurisdictional projects may slip through the process if responsibility for notifying PSCOG is unclear. An example is a proposal to use the interurban right-of-way for a bicycle trail that would cross four jurisdictions' boundaries and operate on the PUD's right-of-way.
3. Projects already beyond the SEPA review stage may proceed without any notification to PSCOG. This process has resulted in the loss of one potential station area in which a massive project, approved several years ago but as yet unbuilt, was suddenly constructed, to the surprise of the right-of-way agreement participants.

Solutions to these loopholes are emerging. In the first two cases, the affected jurisdictions have been so conscientious that early notification of a number of important projects has occurred. Every effort is made to remind local reviewers of the review process so that the process keeps working.

A solution to the third loophole and to the potential problem of local agencies' simply forgetting to notify PSCOG about a project is being explored. One possibility, although expensive to develop and update, would be a land development status inventory of the key parcels along the right-of-way. However, such an inventory would give notice of projects already in the pipeline that would never ordinarily come up for right-of-way review.

Reviews to Date

To date, the review process has been successful in the following ways:

1. The Interurban Trail project was brought to the attention of the NEXT Project early in its development so that trail planners were aware of potential right-of-way conflicts; the PUD was reminded of its agreement to preserve the right-of-way for high-capacity transit; and NEXT Project staff were added to the Trail Project task force for the balance of the project. In the end, the PUD issued a revocable use permit for the trail, reasserting its commitment to hold the right-of-way for future high-capacity transit use. Further, the trail planners, working with the NEXT Project planners, ended up understanding each others' safety, construction, and operational issues, so the two projects may be developed side-by-side.
2. A developer proposed an apartment complex that intruded into the PUD's right-of-way near Everett. The right-of-way review process caught the intrusion and notified the PUD, which had not been aware of it. The project was redesigned. As a result, high-capacity transit right-of-way setback standards are being developed.
3. The State DOT and the PUD had been negotiating to expand a park-and-ride lot that lies on the interurban right-of-way. The expansion was predicated on a proposed perpetual easement for high-capacity transit use. Because the NEXT Project strongly supported the easement concept, the project went ahead.
4. A major developer is proposing a mixed-use development at the site of a proposed park-and-ride lot to serve a proposed station. After initial discussions, the developer pointed out that the site would not support a public station-oriented parking facility in addition to the private uses planned. This defect may affect the location of a future station or it may be possible to negotiate a public access easement to the station from the development and from the bus stop that serves the development.

Special Studies

The Right-of-Way Reservation Program also authorized any of the signators to undertake special studies to help preserve rights-of-way or in other ways support the intent of the agreement.

The Station Area Studies

Since the special studies concept was proposed, SNO–TRAN has undertaken a series of station area studies designed to introduce high-capacity transit planning considerations to affected jurisdictions. These studies have been jointly sponsored by SNO–TRAN using UMTA Section 9 funds, the affected jurisdictions, Community Transit, and PSCOG. In addition, in-kind support is provided by the State DOT, the county, and jurisdictions neighboring the study area through staff participation in the study advisory committee. To date, the studies' budgets have averaged $50,000. The studies have taken about 9 months to complete.

Under the station area study program, the I-5 corridor between the county line and downtown Everett, a distance of about 17 mi, has been divided into four overlapping study areas covering the portion of the corridor in each of four jurisdictions: Mountlake Terrace, Lynnwood, Snohomish County (unincorporated area), and Everett. The studies for Mountlake Terrace and Lynnwood are complete; the Snohomish County study will be completed at the end of 1989. The Everett study will be begun in 1990.

The station area studies are preplanning studies. A second round of station area studies is assumed once the high-capacity system is under preconstruction design. This concept was adopted from the Portland, Oregon, MAX system planning program. At this early stage, the studies are designed to provide the following information to the affected jurisdictions:

1. Possible station areas are identified, but are purposefully vague in their definition because identifying specific sites would be premature. The station area is shown as a circle, about a quarter-mile in diameter (the walking distance standard for station planning), located in a general area where a station might be effectively located.
2. Information is collected about the existing zoning, environmental considerations, traffic, and access issues (development potentials, major public or private project impacts, and population and traffic forecasts).
3. Potential station impacts are identified including impacts on the environment, quality of life, economic development, traffic, and the overall transportation system.
4. Site-related issues that might be fatal flaws or major enhancements for a station are explored. These issues include access barriers (grade problems, hazardous pedestrian access); the proximity of major user groups (e.g., schools and apartment complexes); and environmental problems (wetlands).

Recommendations for comprehensive plan changes and new high-capacity transit-supportive land use and transportation system policies are also provided.

To date, the use of the station area studies by the local jurisdictions has been limited. Mountlake Terrace's study, completed in January 1988, spent many months under analysis by the planning commission, which recommended city council adoption of most of the study's recommendations. The community's negative reaction to the proposed actions (which would have opened the way for possible creation of mid- to high-density transit development zones and transit-supportive planning) forced the council to reconsider which elements of the planning commission's recommendations it would amend into the comprehensive plan. Finally, in September 1989, the council amended the comprehensive plan to allow for compatible site planning and transportation system improvements, but held off instituting higher density zoning until the build decision is made.

The Mountlake Terrace community's reaction reflects in part the lack of public information provided during and after the study as well as general community fears about growth, higher density development, and loss of quality of life. A theme raised by the community, and subsequently repeated elsewhere along the corridor, was outrage that communities with stations would become nothing more than access routes for neighboring communities not directly served by the system. The message was sent that if the station in Mountlake Terrace could be reserved for the city's residents, much of the opposition would be withdrawn. What was interesting was that the same people who advocated bus and rail transit protested the proposed siting of high-capacity transit facilities and the type of development needed to support the system.

The second station area study, prepared for the city of Lynnwood, has just begun planning commission review. This study may produce a different outcome than the Mountlake Terrace study did. Lynnwood, which has a retail area of primarily single-story minimalls and no defined downtown, is considering using the concept of a downtown Lynnwood station to help create a pedestrian-oriented, mixed-use downtown. The voter initiatives in Seattle and Bellevue, capping office construction, may bring major development to Lynnwood, 17 mi north of Seattle. The station area recommendations for a business-oriented downtown, mixed with retail and residential elements around a station, may help structure thinking as development pressures mount.

Legal Research

As part of the station area study program, a series of legal research projects has been conducted. A well-known land use planning law firm in the area was placed under contract to provide papers on issues of interest to the local jurisdictions. To date, two papers have been prepared: (a) "Scope of and Limitations on Land Use Regulatory Authority for Ensuring Development Consistent with Proposed High Capacity Transit"; and (b) "Legal Constraints on Property/Air Rights Acquisition for High Capacity Transit."

Additional legal research will be undertaken on request of the participating jurisdictions.

Integrated Work Program

The station area study program has also served as a catalyst for planning coordination. At the outset of the Lynnwood study, it was determined that 10 major corridor-related transportation projects, being conducted by six agencies, were in progress or scheduled to begin immediately. In response, an integrated work program was developed as the first task of the station area study. The following actions are examples of what the integrated work program did.

1. It created a mechanism for sharing information between the projects even to the extent of outlining data requirements for each project and possible sources from other projects.
2. It caused several projects to be rescheduled and redefined to eliminate duplication and to move work programs to later stages on the basis of work done by earlier projects. For example, the station area study was used to scope possible station and other high-capacity transit sites. Community Transit's transit center study was held up until the station area study recommendations came in so that transit center siting could use the recommendations as a base. The State DOT's park-and-ride location study was restructured and rescheduled to become a design study, building from the transit center's findings.

The result promises to be an approach to preserving right-of-way for the HCT system through the acquisition of land for interim transit facilities that are desperately needed today. Even if the future HCT system fails to use those facilities, two current projects were furthered by this simple concept.

CONCLUSIONS

The right-of-way agreement is popular with public officials and the media. Whether this can be a measure of long-term success or not, is not clear. What is clear is that it gave local officials an opportunity (a) to agree on something to support and (b) to do something productive during the long wait for the regional system to develop.

The agreement has also been fairly easy to understand and to use. The review process has been integrated into SEPA reviews of local jurisdictions with apparently little difficulty. Public officials have become aware of the right-of-way and are advocates for it, something that shows up as they consider permits for projects that might affect it. The station area studies are also popular. There has been little difficulty in securing funding or eliciting advisory committee participation.

One side benefit of the agreement development process was the cadre of committed, informed, jurisdictional staff that it helped form. Since the 18 months of working together on the agreement, that same group of people has continued to work together as the technical advisory committee to the NEXT project, meeting monthly to staff the station area studies, check the right-of-way reviews, and coordinate other projects occurring in the corridor.

The agreement will have served a purpose even if the high-capacity system is not built. First, it has brought public transportation into the local land use decision-making process and has begun to build it into comprehensive plans. Second, it has helped sharpen public official awareness that transportation issues may be more manageable when addressed within partnerships. Finally, it has helped bring to the fore the reality that land for community facilities—in this case stations and park-and-ride lots—is disappearing much more quickly than had been recognized. As an educational device, the agreement has proved its worth.

There are problems too. The ultimate effectiveness of the strong antigrowth movement in the county and the region can not be predicted. The reaction of the Mountlake Terrace community to the prospect of higher density development around stations was one manifestation of that antigrowth sentiment. In the November 1989 election, one of the Mountlake Terrace council members who had staunchly supported the high-capacity program was defeated. As she had also championed other projects that would have affected the single-family residential character of the city, the degree to which her high-capacity system position affected the vote is unclear.

The lack of an adopted regional high-capacity system plan with such features as specified alignments, adopted technology, and formal station siting criteria means that regardless of their best intentions, public officials are unable to expedite approvals of projects. Developers cannot be required to comply with something that is still conceptual.

The context may change. In November 1988, the Seattle Metro Council acted to rescind the 1986 action putting aside rail planning and to take the lead for the development of the regional rail system. In the fall of 1989, Metro began a $15 million series of studies to move toward the design of the initial system. At some point in the foreseeable future, it may be possible to move the right-of-way agreement from its nonbinding status to an action status.

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Conceptual Model of the Fixed-Guideway Decision Process

MARK A. EURITT, M. ALLEN HOFFMAN, AND C. MICHAEL WALTON

During the last two decades, a number of cities have developed or considered fixed-guideway systems. Because the actions of eight metropolitan areas have been involved in the fixed-guideway evaluation process, a conceptual decision model could be based on their experiences. The decision process for four of the areas—Portland, San Diego, Sacramento, and Santa Clara County—resulted in the construction of light-rail transit systems; two of the cities—Houston and Los Angeles—opted for a system of transitways, and two cities—Milwaukee and Columbus—chose not to develop a fixed-guideway system. The decision process for a fixed-guideway system is a complex interaction of various issues and actors. The principal issues affecting fixed-guideway decision making are social, systemic, and funding. Social issues are external system factors such as economic development, land use impacts, and energy issues. Systemic issues, which are the technical criteria used in alternatives analysis or comparable studies, include capital and operating costs and ridership estimates. Funding issues pertain to the availability of financial resources and their impact on decision making. Actors are categorized as the public (local citizens, including special-interest and community groups), local officials (persons or groups designated to evaluate fixed-guideway alternatives), and institutions (federal and state funding agencies and various state transportation departments and commissions). The case study analysis indicates that technical criteria are not critical factors in fixed-guideway decision making. Instead, the decision process is dominated by political interaction among local, state, and federal officials guided by social benefits, actual or perceived, and systemic issues that influence funding for transit alternatives.

As urban transportation problems continue to mount, cities will be forced to make major decisions affecting the economic and environmental well-being of their communities. During the 1980s, a number of cities constructed fixed-guideway transportation facilities. Currently, there are over 24 cities in various stages of planning and design of fixed-guideway systems (*1*).

The purpose of this paper is to identify key decision factors and issues used in selecting a fixed-guideway system. The findings are the result of a research study conducted by the Center for Transportation Research, University of Texas at Austin, for the Capital Metropolitan Transportation Authority (Capital Metro). The objective of the research was to identify critical evaluation criteria in the selection of fixed-guideway systems. Capital Metro officials anticipated a set of objective technical criteria that could be used for projecting the success or failure of a fixed-guideway system. Eight cities, representing three different decision outcomes, were selected for in-depth study. Four cities—Portland, Sacramento, San Diego, and San Jose—selected light-rail transit (LRT) as the preferred fixed-guideway alternative. Houston and Los Angeles opted for a system of transitways or high-occupancy vehicle (HOV) lanes. Milwaukee and Columbus studied fixed-guideway alternatives and chose not to construct a new system. These cities are identified as "no-build."

Following analysis of the case studies, it was concluded that technical issues did not determine the outcome of the fixed-guideway decision process. Consequently, it was not possible to identify a set of critical values for evaluating alternatives. What emerged, instead, was a conceptual model of the decision process. Within the model, it is possible to identify critical elements and factors affecting implementation of fixed-guideway systems. This model should assist decision makers in their review of fixed-guideway alternatives.

SUMMARY OF CASE STUDIES

Portland

The Portland Standard Metropolitan Statistical Area has an estimated population of 1.25 million persons (1980 census) under the jurisdiction of more than 40 governmental entities. Formed as a municipal corporation in October 1969, the Tri-County Metropolitan Transportation District (Tri-Met) serves the transportation needs of the urban portions of Multnomah, Washington, and Clackamas counties. Tri-Met is supported by a payroll tax of 0.6 percent (60.2 percent of total revenues), operating revenues (27.2 percent of total revenues), federal operating assistance (4.8 percent of total revenues), and other miscellaneous sources (7.8 percent of total revenues). The district currently operates the regional bus system and the Metropolitan Area Express (MAX), Portland's LRT system.

The decision to construct the MAX was the product of a complex history. Beginning as a crusade to terminate construction of the proposed Mount Hood Freeway, the construction of the 15-mi MAX resulted in one of Oregon's largest public works endeavors (*2–5*). Although decision makers used traditional criteria for evaluating fixed-guideway alternatives, an analysis of the Tri-Met fixed-guideway evaluation process reveals that nontechnical issues were largely responsible for the selection of LRT as the preferred alternative.

Tri-Met officials cited reduced operating costs, based on projected ridership, as a critical issue in their support for LRT

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(*3*). However, several factors inflated the ridership projection: (a) high growth, (b) expensive gasoline, and (c) a 10-percent mystique factor. (Not surprisingly, MAX ridership in 1988 was less than one-half of the 1990 projection.) In reality, the decision to implement an LRT system was based on issues other than operating and cost factors. These issues were inferred by the Tri-Met Board, when it indicated that there was strong public support for LRT.

Public support for LRT from the city of Portland was based on environmental and land-related issues. The city had recently completed a transit mall to enhance the redevelopment of the downtown area as well as provide a focal point for transit-pedestrian interaction. City support for the busway, one of the two principal alternatives, was substantially diminished when it was learned that the busway option would inundate the mall with over 500 buses per hour in 1990—the mall's peak-hour capacity is 260 buses per hour. The city was particularly disturbed about the potential noise and exhaust impacts of diesel buses. Another primary reason cited by the city for support of LRT was its ability to focus and enhance the city's development and redevelopment plans. Overall, the city believed LRT would have a positive impact on development. Other municipalities and county officials in the Tri-Met service area cited comparable reasons for supporting LRT.

Although projected operating costs and ridership pointed to LRT as the preferred alternative, in truth, other nontechnical issues were more significant. Strong public support and the availability of funding through reallocation of money from the Mount Hood Freeway, coupled with strategic political maneuvering by state and local officials, determined the fate of LRT in the Portland area.

Sacramento

The Sacramento Regional Transit District (RT) is charged with providing public transportation to over 900,000 persons in the Sacramento metropolitan area. The FY 1989 RT operating budget is $34.5 million. Operating revenues are expected to make up 26.8 percent of the $34.5 million, with passenger fares accounting for 97 percent of the operating revenue. Nonoperating revenues account for the remaining 73.2 percent of the FY 1989 budget; federal and state sources supply 9.3 and 63.3 percent, respectively, and the remaining 0.6 percent is scheduled from other sources.

RT operates two LRT lines in corridors extending northeast (I-80 corridor) and east (Folsom corridor) from the central business district. The combined area of the two corridors was studied for Sacramento's alternatives analysis process conducted during the early 1980s.

A primary factor behind Sacramento's selection of LRT was the broad public support that LRT enjoyed throughout the decision process. The local community, including public officials, believed that the ability of rail transit to focus and guide urban development is an important characteristic of rail transit that is not considered in the technical evaluation. Local officials argue that because of the permanence of rail, LRT has a tendency to attract developers and potential employers to the LRT line and station locations. HOV lanes and buses, which are not necessarily a fixed service, do not have the same ability to attract. Additionally, because the system was primarily constructed within abandoned Interstate and railroad rights-of-way, the effects of construction on businesses and housing were minimal—only eight residential dwellings and three businesses were removed (*6*).

Especially instrumental in bringing LRT to Sacramento was the Modern Transit Society (MTS), which conducted planning studies, remained active on various committees and study teams, and lobbied individual decision makers and groups. Before the draft environmental impact statement was released, the MTS and an RT-sponsored Community Task Force for LRT launched a major campaign to build broad community support for LRT. The community was nearly unanimous in its support for LRT along the two proposed corridors. Overall, 46 different community organizations and the 80,000-member Central Labor Council rallied to the cause of LRT. Indicative of the broad support was a comment by the president of the Sacramento Board of Realtors that support for the LRT option was probably the first issue that his organization and the Sierra Club ever agreed on (*7*). The RT Board and Sacramento Area Council of Governments unanimously supported the LRT alternative, as did 10 of 11 members of the study's policy committee and 8 of 9 City Council members.

Sacramento wanted LRT from the beginning and continued its support throughout the decision process. It was a uniform belief among local decision makers that LRT was technically comparable to HOV (*6*). Key local decision makers believed that the UMTA technical evaluation process and state and federal transportation agency staffs were biased against LRT. Local officials argued that the technical evaluation did not give adequate weight to the less quantifiable positive effects of rail transit, such as improved environmental quality (reduction in noise and diesel exhaust), the superior ridership-generating qualities of LRT, and the ability of LRT to focus and guide urban growth (*6*). The perceived lower operating costs were cited by local officials as an important reason to select LRT.

In conclusion, Sacramento desired an LRT system throughout the study process. The technical analyses did not generally support LRT as the best alternative; however, this alternative was selected because of a strong political and public preference.

San Diego

Between 1970 and 1980, San Diego County was the fifth fastest growing county in the United States. Growing concern over transportation problems culminated in the creation of the Metropolitan Transit Development Board (MTDB) in 1975 to study the feasibility and implementation of a fixed-guideway transit system and to coordinate transit service in the San Diego metropolitan area. Made operational in January 1976, MTDB began the Guideway Planning Study, the beginning of the planning process for the San Diego Trolley, in December 1976 (*8–10*).

Between 1970 and 1975, several planning studies concluded that rail transit should be considered in the San Diego area. Coupled with these studies were state initiatives freeing gas tax revenues and 0.25 percent of the state sales tax for transit. These factors were instrumental in the legislation authorizing the creation of MTDB. The legislation mandated the planning, design, and construction of a guideway (rail) transit system in the San Diego metropolitan area, thereby precluding the study of other fixed-guideway alternatives. Funding for LRT was provided entirely through state and local sources. (Federal funds, particularly UMTA assistance, were not actively sought because local officials believed the San Diego area could not qualify because of low densities, uncongested highways, and undefined corridors.) MTDB's enabling legislation was initiated by the influential state senator James Mills, a strong transit advocate, who also played a key role in the transit funding legislation.

The acquisition of the San Diego and Arizona Eastern Railway Company (SD&AE) rail line was a key factor in the decision to implement LRT and was also an important factor in the selection of the South Bay Corridor. Once the corridor was selected, rail became a highly viable alternative because the infrastructure was basically in place in two major corridors of the region. The relatively inexpensive SD&AE acquisition (108 mi of rail line for $18.1 million) was important, because the MTDB enabling legislation and the policies later adopted by the MTDB required that the selected guideway technology be low cost.

According to the June 1978 *Final Report: Guideway Planning Project* (*11*), capital costs for the preferred alternative, a baseline bus system with a guideway, were expected to total $116.8 million between 1978 and 1995 ($48.3 million for bus facilities and vehicles; $45.3 million for single-track rail facilities and vehicles; and $23.2 million for land acquisition). Actual Phase I construction costs (including single-track facility, 14 rail vehicles, and land) totaled $85.8 million in 1981, nearly 25 percent more than the $68.5 million estimate. After completion of Phase II construction in 1983 (double-tracking and 10 additional rail vehicles), the total cost of the project had come to $116.6 million. Although the planning estimate of $116.8 million and the final cost of $116.6 million appear very close, the initial planning estimate included all capital costs for bus and rail facilities constructed between the initiation of construction and 1995, whereas the actual total of $116.6 million was the cost of the rail facility when construction was complete in 1983.

With the MTDB restricted to developing a rail system, the primary decisions made during the Guideway Planning Project were the selection of the rail transit technology to be tested (LRT, heavy rail, or automated small vehicle transit), the identification of the corridor in which the alternatives (i.e., the various all-bus networks to be combined with LRT) would be evaluated and eventually implemented, and the selection of the preferred alternative. Within the context of this report, the ultimate choice of an LRT system in San Diego was not a choice of LRT versus busway but a choice between LRT and other rail technologies (as well as LRT in combination with various all-bus alternatives). The choice to implement rail was, in effect, made when the legislature created the MTDB, an agency charged with implementing a rail system.

San Jose (Santa Clara County)

Located at the southern tip of the San Francisco Bay, Santa Clara County had a 1988 population of approximately 1.4 million. The city of San Jose (population 637,000) is in the northern part of the county, known as Silicon Valley, a major electronics and high-technology area. Santa Clara County is currently constructing a 20.3-mi LRT line extending from the sprawling industrial parks of Silicon Valley, through the San Jose central business district, to the populated residential areas south of the central business district.

A large portion of the transportation needs of Santa Clara County are provided by the county. The Santa Clara County Transportation Agency (SCCTA) consists of 10 divisions with responsibilities ranging from planning, operating, and maintaining the countywide bus system to managing and operating the county's three general aviation airports. The county is also responsible for the administration and operation of the area's LRT system. The SCCTA transit service area covers 326 mi^2 and serves a population of over 1.4 million. The primary operating revenue for the transit system is supplied through a ½¢ local transit sales tax. Additional funding is provided by state gas tax money and federal formula money (*12*).

When transportation alternatives for the San Jose area were studied in the late 1970s and early 1980s, the area was experiencing major growth from the evolution of Silicon Valley. Experiencing the heaviest growth was the 16-mi-long, 5-mi-wide Guadalupe Corridor, which will accommodate San Jose's LRT system on completion in 1991.

Implementing LRT in San Jose was primarily a local political decision made, in effect, before the results of the technical study. The study served a secondary function—justifying LRT over a busway on the basis of the opinion that LRT was comparable to a busway, not superior. In the eyes of many local officials, LRT represented an investment in the future of the city.

The LRT alternative was superior to the busway alternative in only 3 of 10 cost-effectiveness measures, all relating to operations and maintenance costs: average 1990 operations and maintenance cost per passenger, annualized operations and maintenance cost per passenger, and incremental operations and maintenance cost per incremental passenger. Additionally, according to local sources, the rising costs and uncertain future availability of petroleum were important factors in the decision to support LRT. It was estimated at the time of the draft environmental impact statement that the local electricity supplier generated approximately 40 percent of its electricity by hydroelectric means (*13*).

It was the local opinion that both alternatives were economically comparable. A statement from the *Guadalupe Corridor Preferred Alternative Report* (*13*), however, emphasized the superiority of LRT by implying that future LRT operations and maintenance costs might decrease beyond the 1990 estimate: "these cost-per-passenger (amounts) . . . are only for a single point in time, 1990, and do not consider any future growth in transit ridership and resulting operating and maintenance costs beyond 1990."

LRT received broad local political and public support throughout the decision process. Several protransit members of the County Board of Supervisors also served on the County Transit District Board of Supervisors and the Board of Control for the Guadalupe Corridor Alternatives Analysis, creating a strong base of political support for LRT. Several groups, including the MTS, were very vocal in support of LRT alternatives, whereas community support for busways was virtually nonexistent (although there was substantial support for the construction of new highways). Because of the somewhat universal support among the local constituency, congressional support of the project was strong and the project was funded against the wishes of UMTA staff. This strong base of public support and the local politicians' prorail philosophy were the key factors in the decision to implement LRT.

The local prorail political position was bolstered when results of the technical analysis were made public. Although capital costs for the LRT system were substantially higher, the total costs, which included operations and maintenance costs, indicated that both alternatives were "good investment choices." Also, ridership estimates for the two alternatives were essentially equal; however, the fact that the estimates were said to be high tended to favor LRT over busway because of potentially lower operations and maintenance costs per person. This comparability of modes tended to support the ultimate decision for LRT, because the political and community support was present.

The LRT decision would probably have been more difficult if the results of the technical report tended to overwhelmingly support busway. The ridership estimates were made under the inaccurate assumption that fuel prices would continue to increase and that growth would continue at a high rate. Also, as a result of a state appropriation, the expressway segment of the preferred alternative was later upgraded to freeway standards, dramatically increasing the capacity of an overcrowded highway system. If these new trends and the additional capacity of the highway system had been taken into consideration, anticipated LRT ridership would have been lower and, as a result, the ultimate selection of LRT would have been much more difficult to obtain. A statement made by a local official best sums up the San Jose decision process:

> Certainly, our decision to build a light rail system could not be justified on an immediate economic payback requirement. It was by far the most expensive alternative in terms of capital costs. Its initial ridership expectations were marginal at best. But local political leaders were convinced, rightfully or wrongfully, that only light rail would give them the kind of future quality environment and land use pattern they wanted to see happen. And there was a realization that we're probably building this system for our children and grandchildren. But future generations would look back and thank us for the foresight and vision we had.

Houston

The development of the transitway system was a result of the need to improve mobility in the rapidly growing Houston area. With population increasing by 50 percent between 1970 and 1983, Houston grew more rapidly than any city in the United States. Associated with this growth and increasing mobility problems were a 100-percent increase in the number of dwelling units, a 107-percent increase in employment, a 348-percent increase in office space, a 104-percent increase in the number of vehicle registrations, and a 141-percent increase in freeway vehicle miles traveled (*14*). Generally, the transitway was perceived as a cost-effective way to increase the people-carrying capacity of the congested Houston freeways.

The Houston Metropolitan Transit Authority of Harris County (METRO) is the transportation provider for the city of Houston and 14 neighboring cities and towns. The jurisdiction covers a 1,275-mi^2 area, including most of Harris County. The total revenue for METRO in Fiscal Year 1988 was $277.9 million. The operating revenue was $35.1 million, with passenger revenue making up $33.4 million, or 95 percent. Approximately 14 percent of METRO's total expenses were covered by passenger revenue.

When METRO took over operation of the transit system in 1979, METRO staff envisioned a heavy rail system as a means of reducing Houston's growing congestion problems. In June 1983, however, voters soundly rejected the building of a heavy rail line along the Southwest Freeway. The citizens were unwilling to support heavy rail because it was perceived that few people would be served by the costly system. Also, the public generally had a low opinion of METRO. The agency was perceived as spending money unwisely by hiring an excessive number of consultants, and as uncaring and unresponsive in following up on promises made during the agency's formation in the late 1970s.

Prior to the formation of METRO, UMTA agreed to fund the construction of a contraflow demonstration project in the North Freeway corridor in 1978. The North Freeway contraflow lane was considered a success; bus and vanpool patrons achieved an average daily travel time savings of 15 minutes, and passenger use grew from 1,450 person-trips to 4,600 person-trips per peak period during the first year of operation (*15*). Daily ridership increased from 2,900 to 16,500 passengers between September 1979 and September 1983. The contraflow lane, however, was only an interim solution. Several studies indicated that by 1985 or earlier, off-peak travel demand would increase to the point that the contraflow lane would detrimentally affect off-peak traffic operations. Study findings offered the following options: (a) continue the contraflow lane for an indefinite period, (b) discontinue the contraflow lane without replacement, or (c) replace the contraflow lane with a transitway (*15*). Benefit-cost analyses indicated that construction of a transitway was the best of the three alternatives. Finally, in 1982, the state and METRO agreed to develop a transitway within the median of the North Freeway as a portion of a State Department of Highways and Public Transportation (SDHPT) project to rehabilitate the North Freeway.

The failure of the 1983 rail referendum had a direct effect on the development of transitways within the Northwest and Southwest freeway corridors. With the overwhelming defeat of the rail project, the agency was left without a transit project. As congestion grew worse and the agency's poor image deteriorated even further, METRO had to devise a quick solution. A quick solution was also necessary because METRO was about to lose federal discretionary funds earmarked for the rail project. The Northwest and Southwest freeway transitways evolved as an alternative transit project rather naturally because Houston was heavily involved in developing transitways along the Gulf, Katy, and North freeways and had developed a strong working relationship with SDHPT. The Northwest and Southwest projects were similar to the other projects in that construction of the transitways would coincide with the rehabilitation of the freeways and additional rights-of-way would not be needed.

The decision to construct the Gulf, Katy, and North freeway transitways was made during the economic boom of the late

1970s and early 1980s. The decision to develop the Northwest and Southwest transitways, however, was made during the economic downturn of 1984–1985. During the boom periods, the transitways were touted as effective methods for reducing congestion problems along the freeways; however, during the economic downturn, a major selling point for transitways was their cost-effectiveness.

The development of transitways along the Gulf and Katy freeways, as well as the other transitways, was a result of the need to increase the capacity of the corridor within restricted rights-of-way. An important selling point for the initial transitways approved for the Gulf and Katy freeways (as well as for the North, Northwest, and Southwest transitways) was that the transitways would be constructed in conjunction with the scheduled rehabilitation of the freeways. A lower transitway construction cost could, therefore, be realized. The support and cooperation of the Texas SDHPT was instrumental in development of the transitways.

Congressional and UMTA support for the program has been excellent—the Northwest and Southwest freeway transitway projects have been funded approximately 60 percent with federal discretionary grants involving congressional appropriations. Although federal support has been excellent, it was not pivotal in the decision to construct transitways. In the opinion of one key local official, if METRO had been denied federal funding, either METRO or SDHPT would have discovered another method for continuing the building program.

After approval of the Gulf and Katy transitways, the other transitways evolved rather naturally because of SDHPT and METRO's new transitway philosophy. Additionally, after Houston voters rejected METRO's proposed heavy-rail project in 1983, transitways remained the only viable alternative for increasing capacity within the remaining corridors. Bob Lanier, Chairman of the Board for Houston METRO, has been instrumental in the development of transitways. As chairman of the Texas State Highways and Public Transportation Commission, Lanier strongly advocated the development of transitways as a cost-effective means for increasing corridor capacity. Support for METRO's efforts was enhanced through the formation of an ad-hoc "Super-Group" consisting of the mayor, a county judge, and members of the Texas State Highway and Public Transportation Commission, the chamber of commerce, and METRO.

Los Angeles

Transportation service to the 7.5 million people in Los Angeles and the 81 surrounding communities is provided by the Southern California Rapid Transit District (SCRTD). SCRTD, the third largest transit authority in the United States, operates a bus fleet of 2,577 buses over 240 bus routes and a 10.9-mi transitway for a total route mileage of 2,630 mi (*16*). The total Fiscal Year 1987 revenue for the transit district was $490.1 million, less than the reported expenses of $500.5 million (excluding depreciation and loss on disposition of buses). The overall net loss when including bus depreciation and a June 29, 1986, change in the method of accounting for insurance liability claims was $42.3 million. Its operating revenue of $200.9 million made up 41 percent of the total Fiscal Year 1987 revenue, with passenger revenue ($189.3 million) accounting for 94 percent of the operating revenue. Passenger revenue covered 38 percent of the total SCRTD revenue in Fiscal Year 1987.

The El Monte Busway is a 10.9-mi, two-way transitway operating along I-10 (the San Bernardino Freeway) between the community of El Monte to east of downtown Los Angeles. The $60 million facility (in 1972 dollars) opened to buses in January 1973 and to carpools of three or more persons in October 1976 (*17*).

In the 1950s, the private transportation carriers of the Los Angeles region amalgamated into public ownership under the Metropolitan Transportation Authority, later becoming SCRTD. The conversion to SCRTD in 1964 was conditioned by a mandate to develop a rapid transit system for the Los Angeles area (*18*).

It was not until the late 1960s that SCRTD planners and engineers considered constructing an exclusive express bus facility in the congested San Bernardino Freeway corridor (*19*). This corridor was selected as the busway site primarily because improved transportation was needed in the corridor and an infrequently used Southern Pacific Rail Company line was operating just north of the freeway in the wide median. The railway right-of-way was made available after 18 months of negotiation between SCRTD, Southern Pacific, the Public Utilities Commission, and other affected governmental entities.

The project was funded by the Federal Highway Administration (FHWA), UMTA, California Department of Transportation, SCRTD, and the Southern Pacific Rail Company. It became the first project of its kind to be granted federal highway funds. Prior to the funding agreement, FHWA Administrator Frank Turner personally visited the site. (FHWA provided approximately 65 percent of the funds.) This high-level involvement was instrumental in making federal Interstate funds available for transitways within a basically completed stretch of Interstate highway.

The decision to construct a busway in the San Bernardino corridor was based almost entirely on the availability of federal funding and adequate right-of-way, rather than being the result of the type of transportation planning studies or analyses that have been required in recent years. In the words of a knowledgeable participant in the development of this project, "The El Monte Busway was not the result of an in-depth study, addressing a broad range of policy issues. Rather, the project was a response to an opportunity created by the availability of right-of-way. Admittedly, the San Bernardino Freeway has long been congested during peak periods of travel and was a reasonable candidate for a busway." Also, ". . . the availability of funding and real estate (right-of-way) were the determining factors in the implementation of the El Monte Busway."

Milwaukee

The city of Milwaukee, Wisconsin, had a 1980 population of 636,000, accounting for 66 percent of the population of Milwaukee County. Transportation service for the Milwaukee metropolitan area is provided by the Milwaukee County Transit System, operated and managed through contract with Milwaukee Transport Services, Inc. The transit system boarded over 68.6 million riders during 1987, with total revenue and expenses amounting to $64.52 million. Its operating revenue of $30.14 million accounted for 47 percent of the transit system's total revenue. Passenger revenue ($29.41 million) accounted for 45 percent of the system's total budget in 1987.

Beginning in March 1979, the Southeastern Wisconsin Regional Planning Commission (SEWRPC) conducted an areawide study of transportation needs in Milwaukee County and the surrounding area. The project was jointly funded by Milwaukee County, the Wisconsin Department of Transportation, and UMTA and guided by a 21-member advisory committee.

Initial work involved the development and analysis of maximum extent system plans for bus-on-freeway (express bus), exclusive busway, LRT, heavy rail, and commuter rail technologies. System plans were also developed for four alternative futures—moderate growth, centralized land use (most optimistic); moderate growth, decentralized land use; stable or declining growth, centralized land use; and stable or declining growth, decentralized land use (most pessimistic).

First-stage analysis produced cost-effectiveness revisions to the system plans and an initial screening of transit alternatives. The initial analysis determined that a commuter rail system was only viable under the most optimistic future and also found that a heavy rail system could not be supported in the Milwaukee area because of high capital costs and underuse of the system's potential capacity.

The final analysis involved an evaluation of the remaining technologies—bus-on-freeway, busway, LRT, and commuter rail (analyzed under moderate growth, centralized land use only)—using final system plans under each of the four alternative futures. The advisory committee concluded that, under each of the four future scenarios, the bus-on-freeway, busway, and LRT alternatives were very similar in terms of ridership (each within a range of 2 percent), potential levels of service, operating and maintenance subsidy requirements, environmental impacts, and systemwide energy consumption (LRT petroleum consumption 5 to 8 percent less than the busway plan and 8 to 11 percent less than the bus-on-freeway plan). The only measurable difference between the three alternatives was the cost required for system implementation. The annual net public cost for the bus-on-freeway system in each future scenario, including capital costs and operation and maintenance costs, was 14 to 21 percent lower than the busway plan. The LRT plan was 7 to 10 percent more costly than the busway plan and 25 to 30 percent more costly than the bus-on-freeway plan (*20*).

On the basis of these study results, the bus-on-freeway plan was judged superior because of the lower costs associated with it. The advisory committee, however, believed that the LRT plan would defeat the bus-on-freeway plan if the intangible benefits of LRT (especially the potential to influence land development and redevelopment) were considered. Consequently, the Milwaukee County Executive and Board of Supervisors requested a study to determine how express bus or LRT improvements would address transportation, land development, and redevelopment needs of northern Milwaukee County.

Initiated in September 1984, the Milwaukee Northwest Corridor Rapid Transit Study evaluated six alternatives—three express bus alternatives and three LRT alternatives. Under Step 1 of the evaluation, the three express bus alternatives and the three LRT alternatives were studied individually to determine the best alternative from each of the two technologies. Step 2 involved a comparative analysis of the best bus and best LRT alternatives.

An alignment using an existing rail line was selected as the best LRT alternative. A primary factor in its selection was a capital cost expected to be $3 to $4 million less expensive than an alignment along West Fond du Lac Avenue and $13 to $14 million less expensive than an alignment along North Sherman Boulevard (*21*). Although less costly and less controversial, however, the railway alignment would be less accessible to patrons.

Public outcry against construction of an LRT line along Sherman Boulevard or West Fond du Lac Avenue was also a factor in the decision to select the North 33rd Street railway corridor as the best LRT alignment. In areas near the North Sherman Boulevard alignment, a division of the neighborhood near the proposed LRT line prompted strong opposition. Similarly, the business community strongly objected to the West Fond du Lac Avenue alignment, primarily because of anticipated problems (such as construction inconveniences and loss of onstreet parking) related to the roadway widening.

In comparing the best LRT and express bus alternatives, express bus was determined to be superior with respect to direct costs and benefits. Compared with LRT, the express bus alternative was expected to provide annual operating cost savings of $2.1 million, an annual reduction in the operating deficit of $2.8 million, and a total capital cost savings of $166.7 million (*21*). Throughout the process, UMTA maintained that the LRT system was not cost-effective and could not be justified over the express bus option. Both alternatives, however, were similar with respect to levels of service and transit ridership.

It was determined that LRT would have a substantial effect on development along the LRT corridor. Corridor area development, however, would primarily involve relocation of existing business rather than attraction of new businesses.

On October 1, 1987, the Milwaukee County Board of Supervisors, as recommended by the advisory committee, endorsed the planning report and the best LRT and best express bus alternatives. The board also endorsed implementation of the express bus alternative. Key to the board's decision to select the best express bus alternative (rather than the best LRT alternative) was federal support for a low-capital project and the noncontroversial nature of the express bus alternative. The lack of a current state program to provide transit system capital assistance was also a local reason against implementation of the LRT alternative. Overall, community support for the LRT option was neutral. The implementation of the best LRT alternative remains an option for the future.

Columbus

The Central Ohio Transit Authority (COTA) provides public transportation service to 895,000 people in the Columbus metropolitan area. In FY 1987, the total COTA revenue was $19.3 million, and expenses totaled $34.8 million (excluding depreciation on assets). Passenger revenue ($6.0 million) covered approximately 17 percent of COTA's $34.8 million expenses. With depreciation ($5.4 million) included in the total expenses, the district ended FY 1987 with a $20.9 million deficit. (Because of striking vehicle operators and other union employees, COTA experienced a work stoppage between January 1 and February 9, 1987.)

Since the mid-1970s, the Columbus metropolitan region has conducted several transportation studies examining the feasibility of a fixed-guideway system in the North Corridor, an area experiencing rapid development and increasing congestion problems. Two such studies, *A Long-Range Plan for Transit* (*22*) and *Mid-Range Transit Development Concept for Central Ohio* (*23*), recommended the construction of a busway along an existing railroad right-of-way in the North Corridor. In response to the recommendations of *Mid-Range Transit Development Concept for Central Ohio* (*23*), as well as earlier studies recommending similar solutions, UMTA agreed in 1977 that additional study of the North Corridor was warranted. The report was accepted in fulfillment of the systems planning stage of the alternatives analysis process.

Four alternatives for the corridor [no action, transportation systems management (TSM), busway, and LRT] were ultimately studied. Early in the study process, however, UMTA disallowed continued analysis of LRT with federal money because the alternative was not considered cost-effective (*24*). It was argued locally that LRT should be included so that all available alternatives could be compared. As a result, the Mid-Ohio Regional Planning Commission (MORPC) and COTA, with the assistance of a consultant, continued to evaluate LRT with local funding. UMTA continued to disallow the inclusion of the LRT alternative, contending that a number of incorrect and inconsistent study assumptions meant that the LRT alternative could not even be accurately compared with the other alternatives. Later in the study process, the busway alternative also failed to pass UMTA's cost-effectiveness threshold criteria. Neither fixed-guideway alternative was cost-effective, because ridership estimates were too low in comparison to the anticipated capital expenditure. Related to high capital costs was a decision early in the study process to minimize neighborhood disruption and housing relocation. As a result, railroad alignments were considered the most likely alignments for the fixed-guideway facilities; however, the lack of high-density residential areas within walking distance of the railroad alignments translated into low ridership. An additional barrier hindering ridership was created by an Interstate highway paralleling the selected railroad alignment. The busway alternative (53,200 daily linked riders) generated only a 1-percent increase in ridership as compared with the TSM alternative (52,800 daily linked riders). Although the LRT alternative (58,800 daily linked riders) generated a ridership 11 percent higher than the TSM alternative, local officials felt that the capital spent on the LRT system would be disproportionately high compared to the ridership produced.

In December 1985, MORPC and COTA released *North Corridor Transit: Solutions for the Future*, which documented the results of the alternatives analysis. The report, however, did not recommend a specific alternative. During the months before and after its release, support for the entire project was waning. Local political support began to falter because federal funding did not appear to be forthcoming because of UMTA's dissatisfaction with both fixed-guideway alternatives. Also, unlike residents of cities of similar size in the Northeast, citizens of Columbus did not view transit as a primary need. As a result, no official action on a fixed-guideway system was taken, and applications for federal funding assistance were discontinued. In the words of one locally involved individual, the project "went out with a whimper."

Fixed-guideway alternatives were again studied in the *COTA 2000 Long-Range Plan*, completed in January 1988. During this study, each of the region's eight travel corridors were screened for transit compatibility. Using a generic fixed-guideway system operating under ideal conditions, each corridor was tested and evaluated against a standard set of criteria. The results of the initial screening indicated four corridors warranted additional study.

The next step of the study involved identification of fixed-guideway technologies and their applicability to the Columbus region. Using subjective judgment based on the general characteristics of the technologies and the Columbus region, the following guideway technologies were screened: rapid rail, LRT, monorail, automated ground transport (AGT), intermediate capacity transit, suspended rail transit, exclusive busway, and HOV freeway lanes. The guideway technology screening process indicated that LRT and AGT warranted further study.

The LRT technology was tested in two corridors where railroad right-of-way may be available. It was determined, however, that the LRT options were not feasible because of low patronage estimates. A conclusion of the report states that the existing rail lines hold little use as public transit guideways because of the lack of nearby high-density residential areas and employment centers necessary to generate sufficient ridership. Similar conclusions were found for the AGT alternative.

MODEL OF DECISION-MAKING PROCESS

Overview

The case study analysis of these eight cities indicated that the decision to proceed, or not proceed, with a fixed-guideway system was not dependent on a set of technical criteria like those used in the UMTA alternatives analysis. In fact, the selection and development of a fixed-guideway system was the result of a multifaceted decision process. Consequently, attempts to identify critical values for such criteria as operating and construction costs or ridership forecasts, provide little useful information into the decision process for fixed-guideway systems. The case studies indicate that critical values or specific criteria cannot be accurately contrived from the planning or operation data of a facility, because the decision is so heavily affected by issues other than the findings of the alternatives analysis or related technical studies. Also, upon preliminary engineering or after several years of facility operation, the findings of the initial planning studies are frequently found to be inaccurate. Table 1 presents capital cost and ridership planning estimates of LRT systems in comparison with actual values incurred after construction or after several years of operation. Without adjusting for the effects of inflation, LRT capital costs were underestimated between 26 and 174 percent. Similar results are found for ridership. The San

TABLE 1 LIGHT-RAIL CAPITAL COSTS AND RIDERSHIP

LRT System	Forecast Capital Cost ($ millions)	Actual Capital Cost[a] ($ millions)	Forecast Ridership	1988 Ridership
Portland[b]	143.0	214.0	42,500 (in 1990)	20,000
Sacramento[c]	87.7	176.0	50,000 (in 2000)	14,000
San Diego (South Line)[d]	68.4	86.0	28,000 (in 1995)	23,000
Santa Clara County[e]	187.0	511.5	45,000 (in 1990)	6,200

[a] Cost is at opening of project.
[b] Estimates are from the August 1980 Final Environmental Impact Statement (FEIS).
[c] Estimates are from the Draft Environmental Impact Statement (DEIS). The Preferred Alternative Report estimated capital cost at $112.7 million. The 1988 FEIS estimated ridership at 20,500.
[d] Cost estimate represents capital expenses between 1978 and 1985 in constant 1978 dollars. Cost estimate is from the Preferred Alternative Report. Actual cost is based on Phase I construction (SD&AE acquisition, single track, 14 rail vehicles, and construction).
[e] Actual capital cost is the November 1988 estimate to complete the light rail project. Cost estimate is from the Preferred Alternative Report (*12*). Only one-half of the system was operational in 1988.

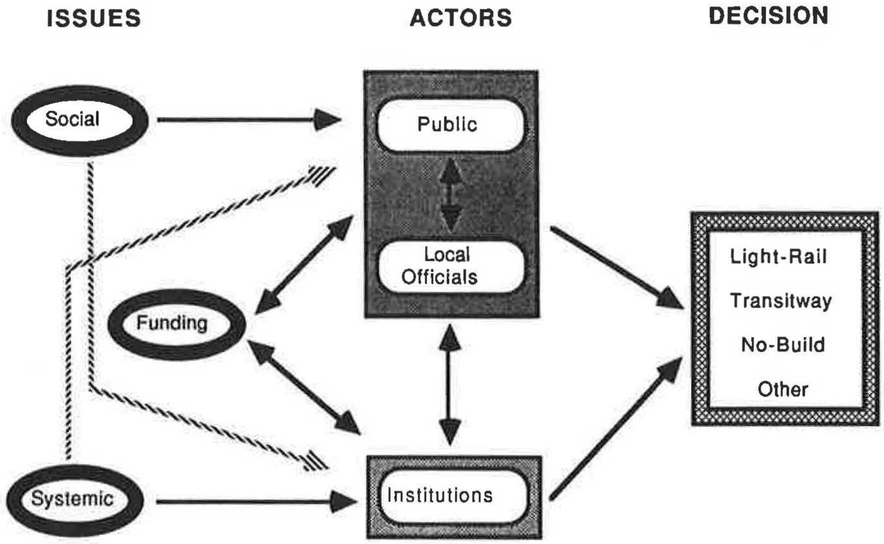

FIGURE 1 Model of fixed-guideway decision process.

Diego South Line, with a planning estimate of 28,000 riders per day in 1995 and an actual ridership of 23,000 riders per day in 1988, appears to be on line in terms of ridership; however, the South Line LRT facility is now a double-track line offering a much higher capacity and level of service than the single-track facility that was originally planned and operated.

There are a number of factors common to the case studies from which to derive a conceptual model of decision making. The model, shown in Figure 1, describes the interaction of various issues and actors in their decision making. Issues generally set the stage or the context for decision making. Actors, who are strongly influenced by these issues, are those persons, individually or collectively, in a position to influence the decision to implement (or not implement) an LRT system, transitway, or transit facility improvement. It is the interaction of these components that determines the outcome of the fixed-guideway evaluation process.

Issues are categorized as social, systemic, or funding related. Social issues are primarily external to the planning and direct operation of the fixed-guideway facility. The potential for economic development, land-use impacts (e.g., removal of housing or businesses), energy issues, and the current or anticipated state of the regional economy are typical social issues. Systemic issues are the traditional technical criteria used in the alternatives analysis or other technical evaluations and include capital and operating cost estimates and ridership forecasts. Funding issues pertain to the availability of financial resources and their resulting impact on the fixed-guideway decision.

Actors are categorized as the public, local officials, and institutions. The public is the general population or constituency of a governmental jurisdiction as well as special-interest groups, community groups, and other organizations. Local officials, principal persons involved in the selection of the locally preferred alternative, are usually elected officials at the city and county level as well as transit board members. Institutions are the federal and state funding agencies, typically UMTA and FHWA, and the various transportation departments and commissions.

The various issues affect actors differently. Social issues primarily influence the desires and perceptions of the public and local officials who would directly benefit (or not benefit) from the implementation of a fixed-guideway system; institutions, however, which are seldom guided by social issues, base their decision to support a project on systemic issues. In each of the three federally funded LRT case study projects as well as the two no-build cities, UMTA did not support the construction of a fixed-guideway facility; the capital costs, operating costs, or ridership estimates, or some combination of these systemic issues, along with other technical factors, did not justify LRT over other alternatives.

The availability of funding affects the local level (public and local officials) as well as the institutional actors that control or make recommendations concerning the allotment of funds. Although the availability of funding is important in the local decision to commit to a major investment, local decision makers have frequently pursued LRT without UMTA financial support. Federal funding, in some instances, was obtained later through congressional appropriations.

Interaction among actors is especially strong at the local level. Seldom have local officials made a decision to support or not support a major capital investment without the support of their constituency. This was particularly true in Milwaukee and Columbus, where there was not active support for a fixed-guideway system. On the other hand, local officials can also be effective in molding public opinion through the news media and community meetings. Interaction among institutions and local officials (and their agents or staff) is common throughout the project planning stages.

Issues

Systemic issues generally pertain to the results of technical evaluation and review studies. Primary systemic issues are ridership, capital costs, and operating costs.

For each LRT case study, actual patronage lagged behind the ridership forecasts (see Table 1). These higher planning estimates usually favored LRT over other alternatives in one or both of the following ways: outright superiority in terms of ridership and lower operating costs. In Portland, a high ridership estimate was strongly influenced by the 10-percent rail mystique factor, anticipated high gasoline prices (which did not come about), and an unexpected recession that severely lowered anticipated population levels. Similar economic conditions in other cities resulted in high ridership estimates for LRT alternatives.

In San Jose, the ridership estimates both for the busway and LRT alternatives were similar; however, the fact that the number was high tended to justify LRT over busway in terms of lower operating costs. Lower operating costs result from the need for fewer train operators, as compared with the number of bus operators, to handle higher loads. Also, the LRT alternative was judged superior to the busway alternative in only 3 of 10 cost-effective measurements presented. All three measurements involved various operating and maintenance costs on a per-passenger basis. In Sacramento, operating cost was the only criteria in which LRT was judged superior, and this factor was promoted heavily by local officials. The results, however, were based on study assumptions that, in conjunction with high ridership estimates, yielded overly optimistic values.

In each of the LRT cities, the capital cost of the completed facility was underestimated (see Table 1). The busway alternative was less expensive than the LRT alternative in both Sacramento and San Jose; however, San Jose promoted LRT by indicating that both alternatives were good investment choices. LRT capital costs were also higher than the other alternatives in Columbus and Milwaukee. The availability of right-of-way was an important factor in lowering capital cost estimates as well as promoting the feasibility of a fixed-guideway facility, even though right-of-way availability did not necessarily promote the implementation of one form of fixed guideway over another.

Social issues affect the decision process but are primarily external to the planning and evaluation studies. These issues are commonly related to the economy, environment, or overall identity of the region.

The ability of LRT to focus and guide urban development was an issue touted by several cities, including Portland and Sacramento. The potential development impacts of LRT in Milwaukee was a primary reason for continued study of LRT feasibility in the Northwest Corridor, even though initial studies indicated that it was not feasible due to excessive capital costs. In all cases, UMTA did not support these local contentions.

Potential impact on properties was also a significant issue. In Portland, public revolt against the construction of the Mount Hood Freeway, which would have removed 1 percent of the housing stock, was a major impetus in mobilizing the search for alternative forms of transportation. Milwaukee business and neighborhood group objections to two proposed LRT alignments that would either remove on-street parking or divide established neighborhoods led to the selection of an LRT alignment that was inferior to other alternatives in generating ridership.

Similarly, the detrimental environmental impacts of buses was an important issue in several instances. City support for the busway in Portland declined when it was determined that the downtown transit mall would be inundated by nearly twice the number of peak-hour buses than the facility was designed to handle and with excessive noise and air pollution. Local supporters in Sacramento felt the superior environmental effects of LRT were given inadequate consideration.

Energy questions were particularly significant for the four LRT systems. Decisions to implement LRT were made during the late 1970s and early 1980s, a period when the future availability and price of fossil fuels were questionable. Because of this uncertainty, electrically powered LRT systems were more attractive to local decision makers and the general public.

The current and anticipated areawide economy has an effect on the local desire to invest in a fixed-guideway system. In San Jose, for example, Silicon Valley was growing at a high rate in the late 1970s and was expected to continue to expand during the 1990s. As a result of the expected growth, high ridership estimates tended to justify LRT over buses because of the potential savings due to lower expected operating costs.

The model identifies funding as another important issue in the decision process. In truth, availability of funding ultimately determines whether or not a fixed-guideway system will be built. The funding can come from a variety of sources, but it has traditionally involved about 80-percent federal money and 20-percent state and local money. However, there are many examples of local transit authorities using other funding approaches. San Diego, for example, wanting to avoid certain regulations and requirements, did not pursue UMTA funding support. The funding issue and its interplay with the different actors is clearly demonstrated in the Sacramento case study. During and following the evaluation process, UMTA voiced opposition to the LRT alternative, arguing that the high costs and low ridership could not justify its implementation. Local officials, however, backed by tremendous community involvement, overcame UMTA objections by generating congressional support. Local and state officials lobbied Capitol Hill to support funding of their LRT. Resulting legislation bypassed UMTA objections, forcing UMTA to relinquish funds for the LRT project.

Unquestionably, there are a variety of issues that initiate or affect the development of fixed-guideway systems, and it matters little whether the impacts are real or perceived. If the public desires a fixed-guideway system, every effort will be used to effect a favorable outcome. The intangible benefits of rail have frequently been touted as an issue that should be considered when conducting a study of transit alternatives.

Actors

The second part of the model focuses on the actors involved in the decision process. Generally speaking, the public are the citizens, individually and collectively, of a community or jurisdiction. Their importance as actors is demonstrated in a number of the case studies. In Houston, propositions for heavy rail were soundly rejected by voters, forcing Metro to consider less expensive alternatives. Included in the public category are business, special-interest, and community groups. The impetus for LRT in Sacramento began with the MTS, a protransit organization. This special-interest group was formed from a number of community groups opposed to construction of new freeway routes in Sacramento. MTS effectively pressured the Sacramento County Board of Supervisors to abandon new freeway construction in several areas and assisted in the North-East Transportation Task Force efforts, culminating in a recommendation to examine the feasibility of LRT. At the other extreme, neighborhood groups along the North Sherman Boulevard in Milwaukee effectively voiced strong opposition to a proposed rail line. Business groups, fearing patron inconveniences due to construction and loss of on-street parking, similarly opposed a rail alignment along West Fond du Lac Avenue. The public is a critical actor in the decision process for fixed-guideway systems. The case study analysis indicates that when public support was lacking, a fixed-guideway system was not developed, and where support was strong, a system was implemented.

The second group of actors, local officials, are the persons, boards, or other entities responsible for activities such as conducting or coordinating transit planning and alternatives studies, approving or disapproving transit plans, and determining funding sources. Public officials are the elected or appointed agents of the community. In each of the case studies, local officials significantly influenced the fixed-guideway decision process. State Senator Mills played a pivotal role in molding legislation to approve the study and implementation of a fixed-guideway system in San Diego. Neil Goldschmidt, first as Mayor of Portland and later as Secretary of the U.S. Department of Transportation, was instrumental in the development of the MAX. Without his efforts it is unlikely that the MAX would be in operation today. Similarly, Chairman Bob Lanier influenced the development of transitways in Houston.

The final group of actors important in the decision model is institutions. This group consists of federal and state officials, including UMTA, FHWA, Congress, state transportation commissions and departments, and governors. UMTA is an important actor in that it controls distribution of important financial resources for transit systems. In nearly every case study, UMTA played a role, positive or negative, in the decision to build or not build a fixed-guideway system. Likewise, state officials affect the decision process. California Governor Jerry Brown's protransit views were instrumental in making state transit funds available for Sacramento's LRT system. The support of Governor Straub of Oregon and his decision to support the withdrawal of freeway funds and their transfer to a fixed-guideway project was critical to the development of the MAX.

The model indicates that in addition to being influenced by issues, the actors also are influenced by each other. This is to say, the public can influence public officials and institutions, local officials can influence institutions and the public, and institutions can likewise influence the public and local officials. None of the actors operate separately, but instead operate in a complex interrelationship. As noted earlier, the decision to move forward with LRT in Sacramento was influenced significantly by the MTS. Local officials were motivated by the activities of this public group and their perception of strong community support for rail transit. Likewise local officials were influenced by Governor Brown's office and his decision to offer funding for an LRT feasibility study.

CONCLUSION

The model reveals that the activities and interaction of the actors, particularly the public and the local officials, occur during a critical stage in the evaluation of fixed-guideway systems. The interplay of these groups is political. In fact, the interaction between the different groups is the nature of the political process. Before the decision of commitment or rejection is made, these groups are guided by a range of social and systemic issues, either perceived or actual.

At some point, the principal advocates of a fixed-guideway system—one of the three actors, generally the public or the local officials—perceive significant social or community benefits from a fixed-guideway system. In some instances the benefits are seen as answers to immediate needs, such as traffic congestion, and in other instances the benefits are believed to be for the future. In either case, particular actors become motivated to support a fixed-guideway system. This motivation is generally translated into action, such as transit studies, mobility plans, or corridor impact studies. During this process, systemic issues assume greater importance. Capital and operating costs and projected ridership values influence to a large degree the availability of funding, especially federal funds.

Systemic issues guide primarily the institutions in their decision making. The dotted line in the model indicates that systemic issues impact local officials and the public to some degree. Local officials recognize that the systemic issues determine, in large part, the availability of funding. This is particularly true in the Portland example, where original ridership estimates were overly optimistic and were re-estimated at a more realistic and much lower level after receiving funding. After the first year of operation, actual ridership exceeded projections, though it was far below the original estimates used in the analysis of fixed-guideway alternatives. Generally, local decision makers consider systemic issues important when they relate to social benefits. The local decision to support a fixed-guideway system is generally made before estimates of ridership and system costs.

Likewise, social issues influence the institutions, although they are not generally viewed by UMTA as important decision criteria. UMTA focuses on the systemic issues, principally capital costs and ridership.

On the basis of this conceptual model and the analysis of case studies, several important conclusions have been drawn about the fixed-guideway decision-making process:

1. The local decision to commit to fixed-guideway systems is often determined by perceived social benefits that may or may not occur, and it is frequently not the product of an objective analysis of alternatives.
2. Public support for a fixed-guideway system is critical. This support is generally developed during the process of analyzing fixed-guideway alternatives. Lack of support or strong opposition generally results in a no-build decision.
3. Funding availability ultimately determines whether the fixed-guideway system is approved. Where local support is strong, barriers to federal support are overcome, and where funding is readily available, the public is inclined to support.
4. There is not a set of critical threshold values that officials use in selecting among transit alternatives, including no-build scenarios. Instead, the decision process is dominated by political interaction among local, state, and federal officials guided by social benefits, actual or perceived, and systemic issues that influence funding for transit alternatives.

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Market-Based Approach to Transit Facility Design

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An overview of guidelines is developed for the planning and design of transit stations, stops, and terminals. These guidelines have been prepared from a market-based point of view. Key concepts for the design of facilities are directly related to promoting the success of development activities and transit services. The underlying philosophy of these concepts provides that transit services and facilities should be designed from a market-based viewpoint. The market—the people and activities that transit serves—is the major determinant of success for transit and private, commercial activities developed jointly with transit. Quality design will create use both for transit and developments with a benefit both for public and private activities. General development policies are discussed and a summary of design guidelines is provided for various transit station types through a range of design phases.

There has been significant interest in increasing cooperation between the public and private sectors in transportation projects during the past decade. Public sector budgets have been strained. The potential for innovative private sector real estate development related to transit has been seen as a way to benefit both public transit and the private sector. In spite of this progress, little formal investigation has taken place into the role of the private sector in public transit projects, into the forms of cooperation these partnerships can take, or into guidelines for the incorporation of commercial activity into public transit projects. Much has been written about joint development as a concept, and a number of specific project case studies have been documented as successful examples of public and private partnerships in transit. However, little guidance is available on how to specifically design transit projects to generate and maximize the potential for strong market-oriented activities at transit stations.

An overview of key concepts for the planning and design of transit stations, stops, and terminals is provided. The underlying philosophy of the concepts is that transit services and facilities should be designed from a market-based viewpoint. The market—the people and activities that transit serves—is the major determinant of the success of transit and of private, commercial activities to be developed jointly with transit.

Private sector planning, particularly retail planning, is highly responsive to market forces. Projects must attract consumers in an increasingly competitive environment. Six generations of design of the retail mall, for instance, have developed a highly responsive, functional, and attractive environment—an environment that, in fact, becomes a standard for other uses, including transit systems. However, a review of the literature on the relationship between market forces and transit facilities offers little information. An understanding of the market and how to serve it should manifest itself in station planning and design, as well as in the areas around stations. Quality design will create use both for transit and developments with a benefit to both public and private activities. Extensive work (*1*) has provided some detailed design guidelines.

A team with engineering, architecture, planning, and urban geography backgrounds developed this paper. Information was compiled from a large number of sources, including site visits to a variety of cities having different types of transit services and varying degrees of success at joint development. Information sources included transit-related literature, human behavioral analysis literature, planning literature—particularly that related to pedestrians and open space—architectural design, design studies from specific transit systems, and real estate information. The objective was to provide a pattern book of guidelines that could be used by transit agencies and local communities for planning and design of transit facilities that maximize market potential. A project sponsored by the University Research Program of UMTA is the foundation for the work.

Basic principles used to develop the planning and design guidelines for transit terminals are provided (Figure 1). These principles state that the market for transit and commercial activities should be the key force in determining transit facility design. In addition, the range of policies is presented that a transit agency could adopt to enhance public or private cooperation for public transportation projects. The policies range from a reactive approach, in which transit agencies have a passive role in joint development, to an active approach, in which transit agencies take an active lead in project activity. A summary of key concepts that may be used for transit station planning and design is also provided.

PRINCIPLES

Several fundamental principles can be used to guide station design from a market point of view. These principles relate to how transit supports and serves markets and activities. These activities can be used to provide more successful transit services. Design guidelines and recommendations that can

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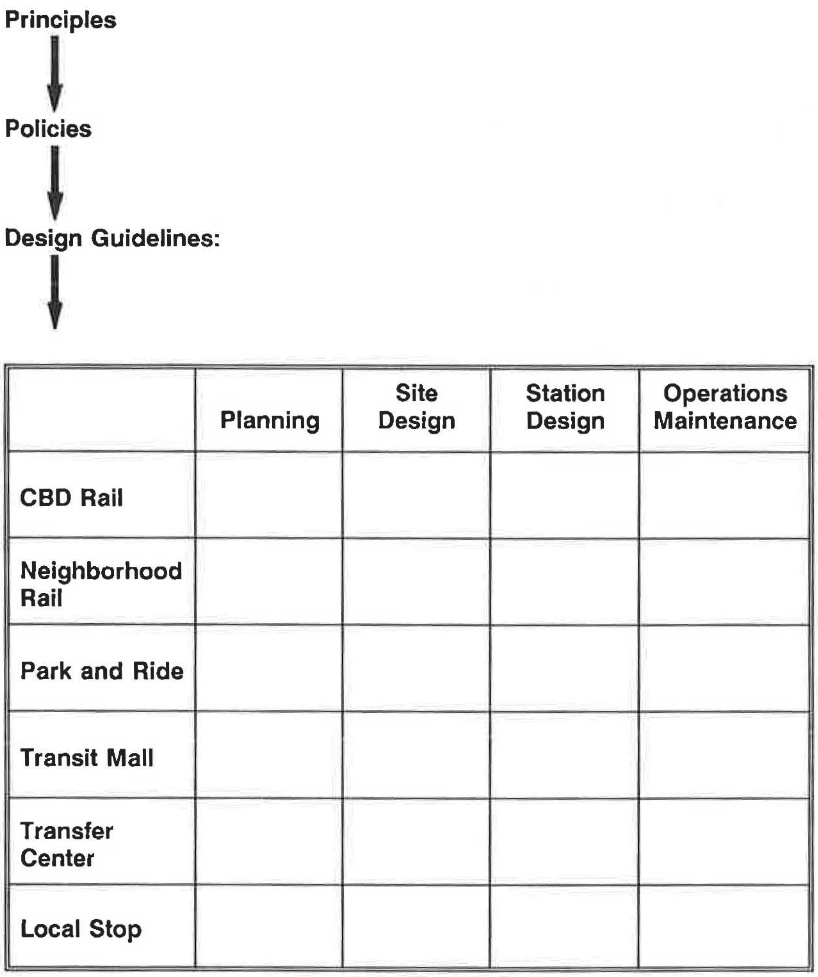

	Planning	Site Design	Station Design	Operations Maintenance
CBD Rail				
Neighborhood Rail				
Park and Ride				
Transit Mall				
Transfer Center				
Local Stop				

FIGURE 1 Framework for design.

lead to a better integration of transit and land use for the mutual benefit of both are necessary.

Principle Number 1: Transit generates business; business generates transit. A symbiotic relationship between public transit and business activity exists. Transit provides quick, convenient access to commercial enterprises and buildings and a concentrated critical mass of consumers for business activities. Business activities and private developments generate trips on transit systems and help to support viable public transportation. To understand and take advantage of the nature of this relationship and to be market oriented are necessary for a successful integration of business activity and public transit.

Principle Number 2: Transit should be an integrated part of activity centers. Transit and activity centers are complementary and should be designed jointly. Transit services often fit poorly, if at all, into major activity centers such as shopping centers, suburban office developments, medical facilities, universities, industrial parks, and even central business districts. To fit transit into existing developments is often awkward. It generally results in either long walks for transit users or convoluted routing for transit systems. An integrated approach to the design of activity centers that actively considers transit is needed. Transit access should be designed into facilities at the initial stages of their planning and design; failing that, potential transit access should be accommodated in the plans of existing developments as projects are modified over time.

Principle Number 3: Access to activity centers should be provided for a variety of modes. Activity centers should be places where people change travel modes. Travelers should be able to arrive at activity centers by walking, automobile, bus, rail, specialized transit, taxi, or other modes. Activity centers are logical places for change of travel mode. The ease of movement from one travel mode to another should be designed into the center. Change of mode activities focuses the flow of users at an activity center and can provide a ready market for commercial activities. The flow of people between modes must be carefully analyzed and facilitated in the design process in order to provide a high-quality facility and to generate usage.

Principle Number 4: The design of transit facilities should be of the highest quality in order to compete with the automobile *and with the standards of quality commercial development.* Transit is in direct competition with the automobile in attempting to attract patronage. Transit can have advantages in time, cost, convenience, comfort, safety, and security relative to the automobile. Even those users who are captive to transit have choices in the long run—to acquire an automobile, to move, to change travel patterns, or not to travel. In order to ensure long-term viability, transit facilities should be designed to provide a quality environment that is competitive to the automobile. Failure to do this may have some short term advantages, but will lead to a demise of public transit services in the long run, and an associated reduction in the quality of the urban environment.

Transit facilities must also compete with private sector environments, not only in terms of capacity, security, and convenience, but also in terms of image, amenity, and vitality.

Principle Number 5: Transit facilities undergo dynamic change over time. They need to be actively managed and designed for change. The design and construction of transit facilities is not a one-time event. Proactive facilities management is required to maintain facilities in prime condition and to frequently adapt and modify them as new situations develop. This process requires a constant effort to modify and expand retail activity, to capture gains in value, and to use excess land areas for new projects. In addition, ease of maintenance and adaptability are important factors to consider in the initial design in order to maintain a consistent high level of quality.

Principle Number 6: Transit should be user friendly. It should be clean, safe, accessible, secure, informative, and comfortable. Transit systems need to overcome traditional negative images. A strong, positive system identity is needed. Facilities design must consider passenger safety and security as well as comfort; while passenger mobility needs are accommodated in accordance with local and national policies. Positive steps are needed to present an attractive image for the services provided and information provided passengers should help them to easily find their way through the system.

ALTERNATIVE DEVELOPMENT POLICIES

A broad range of strategies exists for the enhancement of cooperation between the public and private sectors for public transportation projects. These strategies lie along a spectrum that represents different degrees of activism toward private development by public transit agencies (Figure 2). At one end of the spectrum, the transit agency takes an active role in development (e.g., as a real estate developer), whereas at the other end of the spectrum, the transit agency is relatively passive and may implement transit projects initiated and paid for by the private sector. Between these two extremes, various options with different degrees of entrepreneurial activity occur. The strategies are not mutually exclusive. A transit agency could adopt in whole, or combine parts of, each strategy as part of an overall policy. The strategies will be described and discussed beginning at the passive end of the spectrum (*2*).

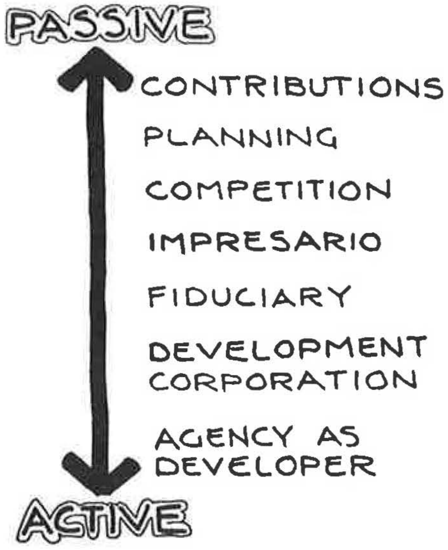

FIGURE 2 Developmental policy continuum.

Contributions

At the most passive end of the continuum, a transit agency could accept contributions from the private sector in the forms of land, services, and monetary contributions to create links to a development project. Generally, the private sector approaches the agency with needs that must be met, such as a transit and real estate project connection required for a private development project to be successful. This approach to the transit agency may be made indirectly through the local municipality in which the project is located, or directly to the agency. The transit agency imposes some criteria over the private project and may modify its plans for a better chance of mutual success. At this point, the project can move ahead if the developer is ready to contribute at a high enough level.

The contribution approach has several advantages. It is legal under existing legislation in nearly all states; it provides a way for the transit agency to receive compensation for project components that are clearly related to private development; it provides developers with a means to get the infrastructure improvements they need if they are ready, willing, and able to pay for them; it is simple and can be done relatively quickly; it can provide high leverage; and it is responsive to comprehensive needs. The disadvantages of this approach are that to relate the benefits of a project to a single development is difficult, and that the developers may not be willing to provide any contributions. Negotiations may lead to different results at different locations, and to use a contribution for some projects and not for others may be awkward.

An example of the contributions strategy follows:

- A substantial suburban shopping center contributes land and the costs of a structure for a bus transfer center. The transit system locates a transfer center at the shopping center, thus generating additional business for the shopping center and convenience for passengers.

Planning

Under a planning strategy, the transit agency expands its planning function, trying to influence local land use and zoning decisions in order to ensure a better environment, a higher quality transportation system, and a sharing of project benefits. Tools that might be used by the transit agency, in cooperation with local government, are expanded access control, zoning, and planning requirements. The transit agency, or local government, may require that a land use plan be developed for an area within a specified distance of a transportation improvement, and that any zoning changes be made before project construction. This policy would ensure that the value of transportation investment is not diluted by inadequate local control of land use, traffic flow, function, or aesthetics. This strategy may or may not have a direct economic benefit like other strategies, but would result in a higher quality transportation system by protecting both transportation investment and the environment. It would also ensure that trip generators are integrated with transit facilities.

The approach could be applied consistently across a community. A critical issue of the proposed policy is the effect on local autonomy. What is the role of the transit agency in relation to local government?

Examples of the land use planning strategy include the following:

- A suburban park-and-ride facility is located in an area that is expected to see rapid growth both in suburban retail and office facilities. The transit system is a major participant in developing a comprehensive plan for the area. Commercial developers are required to locate buildings so they relate to local transit routes and provide loading areas for transit near their buildings.
- A subsidized elderly housing project is proposed for part of the city. The transit housing agencies succeed in changing the project location so that it can be directly served by transit. Project design includes a protected bus waiting area immediately adjacent to the front entrance of the building.

Competition

This strategy is based on the urban development action grant (UDAG) selection process that was used by the federal government to encourage private-sector monetary involvement in urban development projects. The UDAG program was established to help alleviate physical and economic deterioration both in distressed cities and urban counties by fostering public and private partnerships to revitalize cities. Monies were granted on the basis of distress, the project's impact, and the amount of private-sector monies involved. The program used a scoring and ranking system for project selection purposes.

This strategy, as applied to public transportation decisions, would allocate points to transportation projects on the basis of the ratio of private and local dollars to state or federal funds. These points would then be considered along with other factors such as community distress and benefit-cost ratio to select and prioritize projects for the funding agency. The funding agency would reduce costs on the project because of the larger nongovernment share, and also would be able to leverage existing monies to fund additional projects.

The funds would be applied for jointly by the private sector and local government. Competition between projects and localities would lead to a maximum ratio of local dollars to public dollars. The nongovernmental share could be private- or public-sector contributions.

This approach would encourage local communities and the private sector to put together joint public-private development plans that maximize development potential of a transportation project. In addition, the approach would provide incentives, through a competitive process, for localities to increase their share of project costs while providing a greater return on public investment. A potential disadvantage of this approach is that other criteria such as mobility and congestion might be ignored in the decision process if too much emphasis were placed on the financial aspects. A proper balance between criteria would be necessary. The process should also consider the effects of project size as decisions are made.

Example scenarios for this selection process include the following:

- A bus complex is proposed in a major city. Interstate, intrastate, airport buses, and local buses will all use this facility. The city will fund a parking garage for 300 cars ($3,000,000); a developer will build a hotel of 150 rooms ($7,000,000); and some retail ($500,000) can be made part of the $2,000,000 terminal. The land ($1,000,000) is being bought and donated by a local development corporation. The match comes to $11,500,000 for a $2,000,000 state project—a 5.75 to 1 match (or leverage) factor.
- A transit system is considering the expansion of its service in several areas. Local business associations and developers are willing to support several new projects along one of the proposed lines. This line gets priority over alternative locations because of the higher ratio of local to private support for the project.

The Impresario Role

As the transit agency takes a more active role in the development process, the next strategy is the role of the impresario—that is, the agency serving as a broker or middleman to promote, generate, market, coordinate, and seek financing for public-private projects. The agency devises mechanisms to assist development in the form of tax incremental financing (TIF) districts, loans, tax abatements, grants, infrastructure improvements, etc. The benefits of this program are a better environment, higher tax returns, and potential direct contributions. The transit agency, in cooperation with local government, would assist private developers in organizing project packages using a variety of funding and assistance mechanisms. Funding by the federal or state government, if necessary, would eventually be paid back through loans, tax revenues, direct payments, services, and land contributions as in the fiduciary strategy.

The advantage of this strategy is that it allows the transit agency more direct involvement in the development process. With its expanded participation, the transit agency would have a greater degree of control over results. However, the agency may not have the development and investment expertise to design deals that are good for the agency. Some projects may not occur if they become caught up in public debate. In addition, the transit agency may be in competition with local governments that perform a similar role. This system, if adopted, would have to have a strong transit agency and local partnership to be effective.

The impresario approach can be widely used in joint development. Project financing is found from a number of sources (e.g., foundations, UMTA, Economic Development Administration (EDA), private-sector financing, and investment equity) and a mix of uses—retail, public, office, cultural, housing, and transportation—are proposed to generate integrated and viable projects.

Example scenarios of the impresario strategy include the following:

- The transit agency serves as a major force in integrating the local business community, elected officials, and local government in initiating a station modernization program for a neighborhood rail transit station. The project includes a rehabilitated office building and a new parking structure to be built on the site of a vacant building adjacent to the station. The transit agency helps to negotiate an agreement between a local business association and city government for the project. A tax incremental financing district provides funds for station modernization and the construction of new pedestrian links to the office project.
- A transit system works to attract several large trucking firms and a private charter bus operator to locate their maintenance facilities on excess land adjacent to the bus system's central maintenance depot. Private parts suppliers and fuel vendors are encouraged to locate in the area. Discount prices can be offered because of the activity volume in this location.

Fiduciary

The next strategy along the spectrum is the transit agency acting as fiduciary. The transit agency views itself as a guardian of public trust in the administration of an investment program. Transit agency holdings could be managed to maximize the long-term benefits to the taxpayers with the greatest return on agency investment. The rationale behind this approach is that the transit agency can maximize the long-term return while promoting economic development for its transportation investment. The transit agency adopts strategies to recover value gains through holding land and capturing property value increases. For instance, the transit agency could purchase and hold land in a land bank to capture value for future development, see access rights, and provide loans for qualifying private development.

The sale of access rights involves a charge for access to the transit system for developments larger than a given threshold size. Traffic impact fees paid by developers would cover additional costs created by the traffic impact of those projects and the need for additional transit services. Payment may be in the form of cash, land, service, or developer-constructed local improvements. The fees could be set in proportion to the trip generation, square footage, or other factor of a development. TIF used to pay for transportation improvements could be viewed as a type of fee system. An advantage of this fee system is that the fees are not related to the timing of a transportation project because they are collected when the development occurs rather than when the transportation project occurs.

The transit agency would maximize revenue and provide a means to recover value generated by its projects. Policies can be uniform throughout the area so one community would not have an advantage over another. Fees can directly place the cost of transportation improvements on uses that generate the need for the improvements. Direct access to a transit system has a real value and this approach can provide a mechanism to capture the value. However, the agency can wind up holding too much land through speculation and be criticized for unfair competition with the private sector. For these reasons, involvement in land purchases and sales would have to be carefully controlled. Fee systems have a disadvantage because they impose a fee, where in the past fees did not exist, and may be viewed as unfair to new projects. In addition, they may cause jurisdictional problems with local government, especially for projects that have a major impact, but are not located directly in the affected community.

The following is an example scenario for a fiduciary strategy:

- During the initial construction period of a light rail line, the transit system acquires vacant property in the vicinity of several stations located near the edge of the central business district. The property is land that was taken for the project and contains parcels with vacant buildings. The property is leased for parking and eventually sold to a private developer for an apartment complex. Residents of the apartment complex are heavy users of the light rail line for commuting into the central business district, outlying shopping centers, and employment areas.

Development Corporation

Another active strategy is the establishment of public transportation development corporations. These independent government-authorized but autonomous agencies could encourage and assist development related to public transportation projects. Projects would be identified by the development corporation. Negotiations would be made by the corporation on the basis of market factors, and the benefits would operate a better environment with a higher return on investment.

Two types of development corporations are possible: (a) a corridor development corporation could be established that would invest in a particular public transportation corridor, and (b) an area-wide development corporation would seek private sector development to be related to public transportation projects throughout the community.

The advantage of a development corporation strategy is that it is a single-purpose agency that would concentrate all of its efforts on facilitating joint development. The agency would be able to put together projects and serve as a bridge between the public and private sectors. This approach may be applicable only to a limited number of projects and may require considerable lead time to become effective. It could be viewed as a competitor to private development, but with a properly defined charter, it could be a positive influence.

Example scenarios of the use of transit development corporations include

- A light rail system is being built in a city. A corridor development corporation is formed. It has acquired an abandoned 200,000-ft^2 food manufacturing plant and 50 acres on the northwest side of the city, which is adjacent to the right-of-way and a state highway. A kiss-and-ride lot, park-and-ride lot, and a bus transfer center will be developed. The corporation is marketing the building either as offices or a specialty shopping center and will connect the station to the building with a glass-enclosed walkway. EDA, industrial revenue bonds (IRB), and the corporation's own bonds will be used.
- The air rights over the major downtown station will be developed as a parking (500-car), office (200,000-ft^2), and retail and bus transfer station (20,000-ft^2). The rights are provided free to the developer in return for station connections to the street, station areas within the new buildings, as well as other planning considerations.

Agency as Developer

In the last strategy, the transit agency assumes an entrepreneurial role to become a developer in its own right. The transit agency would purchase land, plan, finance, execute, and manage projects for profit. Market considerations determine the investment and the benefits are measured by return on investment. The transit agency would be limited to projects that were in the overall public interest.

The advantage of this approach is that the transit agency both assumes risk as well as receives benefits from its projects. The transit agency would be able to exercise control in order to meet overall goals. The disadvantages are that this type of control may provide unfair competition with the private sector, and that there may not be expertise available to carry it out on a wide scale. Competition between areas could lead to politically acceptable but economically unsound projects. In addition, the extra level of bureaucracy and the requirements for an open process may inhibit projects more than it helps them.

Example scenarios of the agency as developer strategy include the following:

- A transit agency needs new office facilities and purchases a tract of land near one of its stations. A new building that will be occupied by the transit system (40 percent of the space) and by private firms will be constructed at the site. The building will include retail shops on the first two floors. The transit agency finances the building through bonding and capital grants. The bonds are paid back through rental income at the property.
- A new garage and central maintenance facility are needed by the transit system. A large site is available and a new facility is built. The new garage is also used for maintenance by the city sanitation department, a private school bus operation, and several handicapped vehicle operators. Space is leased out to the users. A system is developed to enable the transit system to perform maintenance activities for the other users and the other users to do other work for the transit system. A centralized parts depot is used by all agencies that occupy the building.

KEY CONCEPTS

A major output was the extensive development of guidelines for transit stops and stations. These guidelines range from basic questions of systems planning, such as location, joint development opportunities, and intermodal connectivity, to issues of site planning, stations building design, and operating and maintenance. Issues and guidelines also apply to a variety of locations and modes—central area rail terminals, neighborhood rail stations, transit malls, park-and-ride locations, transfer centers, and local bus stops. Each facility has a market that can generate an environmental response. Even a local bus stop can contain a newspaper box and shelter. Because of space limitations, it is impossible to include all of these ideas. Nonetheless, it is possible to summarize certain key concepts that emerged from the study.

Take the Customer Viewpoint

Transit services exist to serve the needs of their users. Transit facility planners and designers need to think like users and understand what barriers and difficulties users encounter and seek ways to overcome them.

Seek Out and Use Expertise in Development and Property Management

To maximize potential for joint development and shared facilities, working with people who fully understand the development process and how to make projects successful is helpful. One cannot expect real estate people to be knowledgeable in the nuances of public transit, or expect transportation planners to design successful retail or commercial projects without some help.

Use Site Selection To Create Value

Location of stations can follow two approaches. First, stations can be located to serve well-established neighborhoods. Developers should find station sites in neighborhoods that have a mix of high residential densities and commercial development within the market area around the proposed station.

An alternative approach is to locate stations in underdeveloped areas to stimulate new growth and development. New development may follow in the form of high-density residential, shopping centers, and office space (see Figure 3). Transit service could be integrated with other land uses at the site to maximize access to residences and activity centers within the market area. This access in turn could stimulate further development in the surrounding neighborhood. In such a situation, the transit system should be actively involved in seeking development projects. Land banking at station sites may be a way to help influence future development projects.

Understand Market Areas

Studies have shown that the average driving access distances for express bus ridership generally range from 3 to 6 mi,

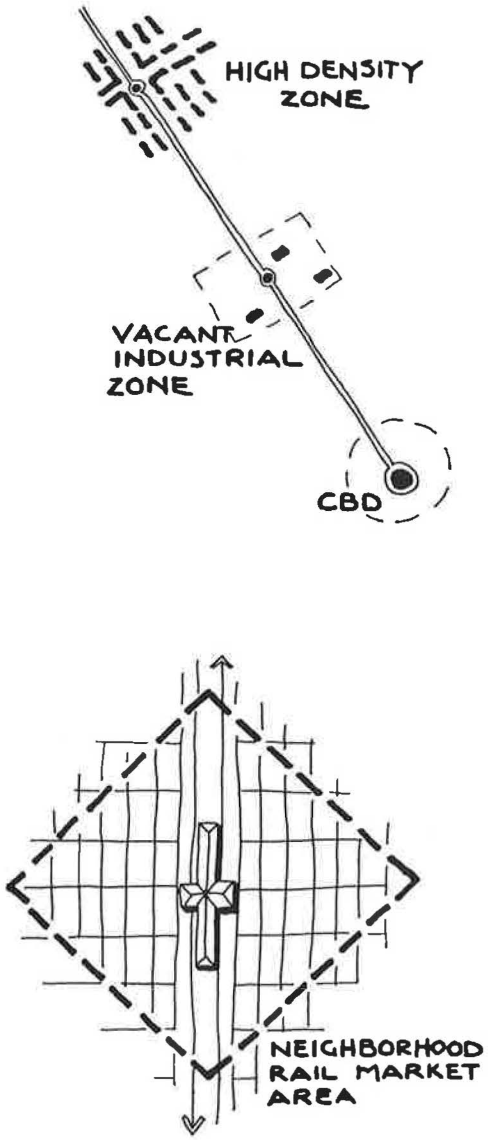

FIGURE 3 Key concepts: use of vacant areas and market areas.

depending on distance from the central business district (CBD). Auto-based access for rapid transit has been shown to vary with the distance of the station from the CBD. Median access distances range from 2.5 mi at 10 mi from the CBD to 5.0 mi at a distance of 40 mi from the CBD.

Average driving distances will be greater for park-and-ride facilities at the route terminus than at those located along the route. At intermediate stations, the market area for park-and-ride facilities is larger in the direction away from the CBD (or other terminal node) because passengers are reluctant to backtrack to the facility.

Pedestrian access distances generally are not greater than ½ mi (see Figure 3). The distribution of passengers choosing to walk to the station decreases rapidly with distance. Activity centers should be placed well within the ½-mi limit.

The boundaries of the walk-based market area will reflect the street network due to limited path choices for pedestrians. In grid systems, the market area will be diamond-shaped. However, the shape and extent of the market area can be altered by the following modifications:

- Introduce mid-block crosswalks and grade-separated walkways over busy streets;
- Alter signalization at intersections to increase pedestrian times traveling in the direction of the station; and
- Provide exits at each end of the platform (*3,4*).

Increase Consideration of Transit in Commercial Development Decisions

Although transit access is often a low-priority factor in the site selection by most developers, it will become increasingly important as traffic congestion increases and conditions to mitigate traffic are levied on new developments, or if energy costs increase substantially.

When a new development is located within an existing activity center, the cost of providing public facilities and service to the development will be lower than if it is located in an undeveloped area. Transit systems should encourage commercial and industrial development to locate in existing urban activity centers, where public facilities and services are already in place or needed improvements can be provided cost-effectively.

Clustering activities also results in a concentration of trip ends. For example, when a recreation complex, health unit, public library, and senior citizens' center are all situated adjacent to a shopping mall, the transit routes that serve the shopping mall also allow people to travel to the other activity centers without transferring (*5*).

Actively Seek To Have Transit Needs Considered in the Land Use Design Process

The incorporation of transit route planning early in the land use design process will, in most cases, ensure that walking distances to transit are kept to acceptable levels. Community planning and road system design should also provide for the incremental extension of transit routes without the need to restructure or substantially revise existing service.

The following guidelines may be useful in planning a street network which can be efficiently served by public transit:

- To connect clusters, design arterials, and transit service in advance of development;
- Encourage neighborhood and service area designs that minimize street lengths and the percentage of area devoted to streets;
- Apply suitable roadway geometries to accommodate bus turning maneuvers;
- Ensure that streets identified for possible transit usage be structurally capable of supporting the weight of transit vehicles;
- Sidewalks should be provided on at least one side of the street carrying transit. Sidewalks and an attractive pedestrian environment are particularly necessary on collector and arterial roads;
- Bicycle access to transit centers, park-and-ride lots, freeway flyer stops, and other major bus stops should be encouraged by local jurisdictions. Wide curb lanes (13 ft, minimum)

or striped bike lanes should be considered for major streets leading to transit facilities (*5*).

Maximize Joint Development Opportunities

Transit terminals can present significant opportunities for major joint development activities. The large volume of people using a station provides a market for retail activities, office complexes, and hotels. In a number of cities, major development projects have been implemented in coordination with transit terminals (Figure 4). The results can be mutually beneficial with successful private development supported by transit activity and increased transit system usage related to more intensive land use activity. Cost sharing by the private sector or payment for access rights can be a major source of funding to the transit system.

If possible, station locations should be coordinated with strong retail centers and the development of proposed centers. Connections to these centers can be retail oriented. In more severe climates, these links, both underground and aboveground, may stretch for a number of blocks and even connect separate station locations.

Facilitate Pedestrian Access to Stations

The maximum walking access distance has generally been observed to be less than ½ mi. Passenger demand will be significantly influenced by the level of office and retail space available within a half-mile walk of the station. Since the distribution of passenger demand over distance follows a distance decay function, passenger demand will be strongly influenced by the level of activity within the immediate vicinity of the station. For activity centers located further from the station, pedestrian linkage to transit can be facilitated by extending the pedestrian range.

- Introduce open spaces and walkways within blocks to reduce network distances to the station—particularly in the direction of demand generators such as high-density office and retail developments;
- Introduce midblock crosswalks and grade-separated walkways over or under busy streets;
- Construct enclosed skyways or underground walkways in cities with cold winter climates;
- Alter signalization at intersections to increase pedestrian times traveling in the direction of the station (*4,6*).

Maximize Connections to Other Modes of Travel

Transit facilities can serve as the focal point of large transit systems for a variety of modes. The station can serve as the primary connection between commuter rail service from the suburbs and local rail service in the form of either heavy- or light-rail service. This extends mobility for incoming travelers within the city. Connections should also extend to local and express bus service. Specifically, the station should consider the following:

- Provide off-street auto access for parking and for dropping off passengers. Where possible, include parking structures with access to the station, surrounding office buildings, and shopping centers.
- Provide platforms both for commuter and heavy-rail lines, light rail, and bus stops in the station or station vicinity with clearly defined pathways between them.
- Align local bus routes within the immediate area to serve the station. Where possible, construct bus bays and passenger loading areas within the station development.
- Provide intermodal transfer passes to increase passenger mobility throughout the system.
- Provide areas for taxicab and specialized handicapped vehicle pickup around the station.

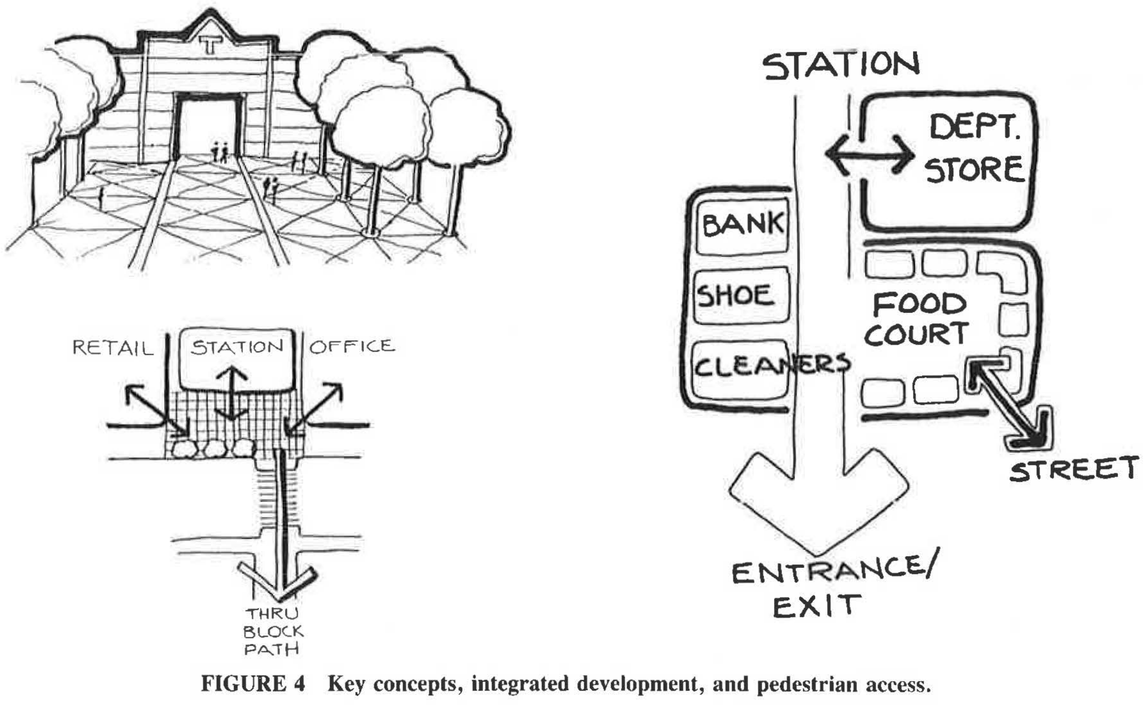

FIGURE 4 Key concepts, integrated development, and pedestrian access.

- Provide additional space for other modes involving unscheduled service, such as charter buses and limousine service, to maintain easy access to the station.

Design in Context of Surrounding Areas

Design of the site should be linked with the district in which it is located. A local identity for the system must be provided. An image that is easily recognizable and comfortable, as well as convenient to access from the surrounding community, is a prime consideration.

- Consider the means of access, traffic characteristics, site flow, layout, and location of access streets.
- Design in accordance with topography, demography, surrounding land uses, street axes, existing focal points, land buffering, visual relationships, facades, historic references, and landscaping.
- The potential for expansion must be considered in the initial planning decisions.
- In areas of high density there is often minimal open space. If possible, provide high-density open space as part of terminals in these areas.
- Provide for less formal vending activities at entry plazas of stations. This includes itinerant sellers, kiosks, and seasonal pushcarts (*7,8*).

Separate Pedestrian/Vehicle Domains

Primary consideration should always be given to pedestrians in station areas—safety and convenience. Because of the large number of riders in CBD areas, provision must be made for distinct, conflict-free pedestrian circulation in the site planning.

- Pedestrian paths and circulation should be separated from vehicle circulation and rights-of-way as much as possible and designed for direct access to and between modes.
- Any crossings should be adequately marked with acceptable forms of barriers, including fences, walls, and elevation differences.
- Priority in design is always focused on pedestrian flow as opposed to vehicle movement (*9,10*).

Create Space for Special Events

A transit facility can be an urban gathering place for special events and temporary uses. These could include festivals and street fairs (e.g., noon time concerts, art fairs, ethnic food festivals, flea markets, and open air displays of civic information) as well as seasonal or part time operations (e.g., food pushcarts, flower vending, and street musicians). Active use of the area near transit facilities generates community spirit as well as usage of the transit system. Activity can be sought by local businesses or civic associations, or coordinated through a downtown management district.

Provide a Functional Facility

The functional design of a station is the most critical of all its attributes. The large number of people using stations at peak hours provides a demand that will stress the station. The feasibility of designing to the highest levels of service to meet these loads is prohibitive. A lower standard with high passenger loads requires that functional station planning must be carefully done.

- Platforms and waiting areas should be designed to a high level of service in circulation, waiting, and queuing;
- Provide access for handicapped persons to all areas;
- Provide bathrooms and trash receptacles;
- Provide a safe, secure feeling for users through open design and good visibility;
- Provide materials that are highly durable;
- Plan for phased replacement of materials and systems over the building's life cycle through the use of a replacement reserve fund;
- Use high quality materials and design;
- Provide sufficient areas of landscaping;
- Provide skylights or visual access to outdoors wherever possible.

Provide Orientation and Systems Information

A transit station can have a level of complexity, in terms of the number of routes and connections, that requires a high degree of explanation. The number of users in such a center is high and some will be unfamiliar with the system.

- Provide overall system routing, fares, and local area information at a central location in the building;
- Provide individual route information—a schedule and route map—at individual bus queuing areas;
- Provide an active sign board identifying departure time of buses;
- Provide information services such as a dedicated telephone line or electronic information board in low volume centers, or a manned booth in heavily used facilities (*11,12*).

Provide a High Degree of Passenger Safety

A transit station is a busy environment at peak hours, especially with a timed transfer system in which many vehicles arrive at the same time. The number of elderly passengers also dictates safety requirements.

- Provide easily visible and tactile safety strips at edge of platforms;
- Provide guard rails and guide rails to control circulation at points of crowding;
- Stop signs, crosswalks, and control signals should be appropriately used where pedestrian traffic crosses automobile and bus traffic;
- Consider the needs of special user groups, such as handicapped, children, elderly, etc. With passenger volumes high at stations, the conditions of crowding and crowd flow may cause problems for these groups (*13*).

Provide a High Degree of Passenger Security

A high proportion of transit riders are elderly persons and women. These groups are often the victims of criminal activity. Increased ridership will result with the perception that the transit system is a safe system.

- Provide a design that facilitates surveillance of station facilities. This includes an open design, avoidance of hidden areas, and high levels of lighting.
- Minimize usable areas and entrances to station at times of minimal travel demand.
- Provide transit personnel at station whenever possible. Provide electronic surveillance at times station is unmanned.
- Retail uses, amenities, and other activities will increase security by concentrating and increasing the number of users of the facility (*14*).

Design for Flexibility of Use

The configuration of a transit station and supporting uses should be adaptable to new conditions and usages. Most regional shopping areas are remodeled as often as every 5 to 7 years and the same could apply to transit facilities. Flexibility should be designed into a station so that the transit agency and vendors can quickly change their configuration to respond to a changing market (*15*).

- Provide an open plan in the building and concourse area that allows for future modifications;
- Provide for a generous use of space to accommodate future contingencies;
- Provide utilities that have the capacity to supply additional growth and change;
- Ceiling heights should be used that will allow for future changes;
- Reserve areas with knockout panels for future expansion and development.

Provide Adequate Maintenance

General maintenance of transit facilities, stops, and shelters should be done on a regular basis. Bus shelters deteriorate to a poor condition that detracts from the neighborhood and gives a poor image of the transit system. Glass or plastic panels in shelters should be replaced if they become scratched or discolored and schedule and route information should be updated regularly. Graffiti and broken glass should be cleaned or replaced immediately to prevent further damage. Graffiti-resistant materials should be used as necessary.

Vending machines, newspaper boxes, and public telephones all can be placed in conjunction with local stops. The transit system should require a minimum level of maintenance for them and should be able to order their removal if they are poorly maintained.

Advertising may be placed at local stops, shelters, or benches if in accordance with transit system policy. To maintain a good transit system image, performance standards and aesthetic standards may be necessary in the advertising contract.

CONCLUSIONS

The concept of market-based design of transit facilities has been summarized. Basic principles for facility design and alternative policies for public and private development were presented along with key concepts for facility design. The fundamental viewpoint is that the market—the customers of public transit—should be the driving force in decisions made regarding planning, location, design, operations, and maintenance of public transit facilities. A symbiotic relationship can be developed between public transit and private activity for the mutual benefit of each.

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Improving the Effects of Elevated Transit Stations on Neighborhoods

ARTHUR C. NELSON AND SUSAN J. MCCLESKEY

Effects that elevated transit stations in residential neighborhoods have on the value of single-family homes are debatable. Some contend that the effects are adverse, because transit stations impose noise, traffic, and other nuisances on neighborhoods. These effects result in declining house values. Others contend that stations improve the accessibility of neighborhood residents to commercial activity centers. This convenience results in increasing house values. Which view is correct? Are both influences present? If so, which influence dominates, and what is the revealed price gradient of homes with respect to distance from elevated transit stations? Elevated transit stations in single-family residential neighborhoods in and around Atlanta, Georgia, are analyzed. Transit planning in Atlanta is summarized, design and planning concessions made in response to vocal neighborhood groups are reviewed, a theory that considers both the positive and negative influences such stations may have on single-family house value is introduced, and the association between neighborhood-oriented elevated transit stations and single-family house values is analyzed. Although both positive and negative influences may have been present, the revealed price gradient was positive in the study area. These results suggest that a planning and design process aimed at preserving established neighborhoods may be successful in minimizing the adverse effects of elevated transit stations on single-family housing values.

In 1968, metropolitan Atlanta voters said no to a heavy-rail rapid transit system. The vote was a blow to the Metropolitan Atlanta Regional Transit Authority (MARTA), which had been created by the Georgia General Assembly in 1965. Analysts attributed the failure of the referendum to four factors: (a) voters were not asked to approve a comprehensive transit package but rather a futuristic proposal for a rail system; (b) voters opposed use of property tax assessments to finance the project; (c) voters were uncertain of the extent to which federal participation could offset costs; and (d) voters did not know exactly what they were being asked to vote on, because the plan had been developed with little public involvement (*1*).

Concern about citizen participation in transportation system planning and design in Atlanta paralleled national trends. The neighborhood preservation movement of the 1950s and 1960s was created in reaction to the eminent domain appetites of urban renewal and federal highway programs that literally bulldozed neighborhoods (*2*). Neighborhood organizations also fought plans for airports, sewer and water treatment plants, drug treatment centers, and even hospital expansions that would have disturbed or destroyed neighborhoods. The objective of neighborhood preservation movements was to influence plans of development agencies to stop, slow, or redirect construction of facilities perceived to be harmful to neighborhoods (*3*).

In response, Congress acted to ensure that decisions regarding disruptive public projects would not be made until the implications had been considered and the affected citizens had exercised their "right to participate in decision-making processes which might result in such disruption" (*2*, pp. 112–113). In this environment, Atlanta voters initially rejected heavy-rail transit development. But the environment also led to greater citizen participation in a redoubled effort to create a rail system.

Over the 3 years following the initial defeat, public participation in MARTA planning activities was accommodated. Transit planning focused more sharply on station location, function, and design. By 1971, planners had identified the major functions each station should perform, the principles on which each station area should be located and designed, and the ways in which each station could be designed to reduce adverse impacts on neighborhoods. As a result of citizen participation, twin objectives of station area planning emerged: developing opportunities for the rapid-transit system and protecting established neighborhoods (*4*–*6*).

Transit stations became classified as one of four types: (a) high-intensity, mixed-use stations, primarily in the Atlanta central business district (CBD); (b) community-center stations serving as centers of commercial, office, and higher-density residential activity; (c) transportation interface stations designed to serve commuters; and (d) neighborhood stations, in established low- or medium-density residential areas. A schematic representation of the neighborhood station design is shown in Figure 1.

Neighborhood stations serve established low- or medium-density neighborhoods. The plans for these station areas stress the protection of such neighborhoods by prohibiting new commercial or industrial development in the vicinity of stations except where compatible. Where there are opportunities for development or redevelopment, low- or medium-density residential uses are usually recommended.

Each station plan contained a description of the existing development patterns surrounding the station site; a policy plan, consisting of goals, objectives, and policies to guide future changes in the service area of the station; a concept plan, identifying physical changes that were anticipated and

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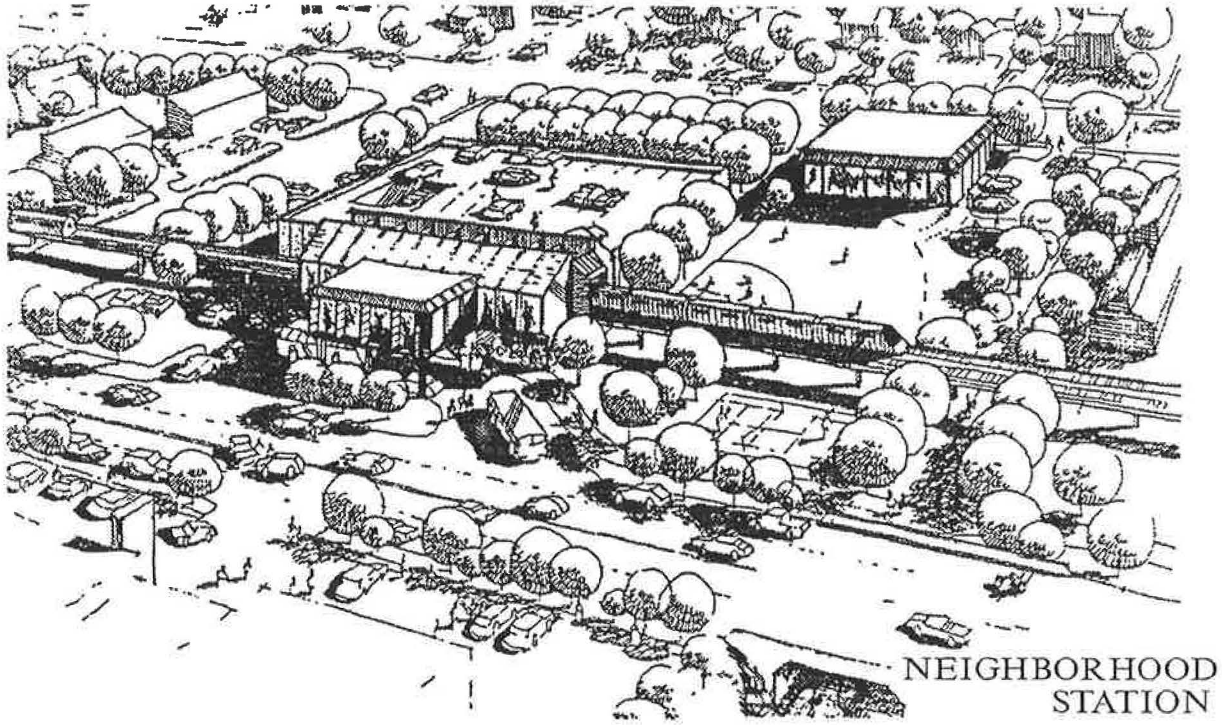

FIGURE 1 **Schematic representation of the neighborhood station design.**

recommended as a result of constructing the transit station; and a design plan, detailing the land use, circulation, and site plan for the immediate area.

The revised MARTA plan included purchasing and improving the existing city bus system, constructing and operating 53 mi of heavy rail, and operating 8 mi of exclusive busway (see Figure 2). Federal funds were obligated, contingent on voter approval of a 1 percent dedicated sales tax to generate local matching funds.

On November 9, 1971, the new MARTA plan was approved by voters in Fulton and DeKalb counties. MARTA began business.

PLANNING AND DESIGN OF ELEVATED NEIGHBORHOOD TRANSIT STATIONS

Elevated neighborhood transit stations have an influence on nearby property values. The objective of the planning process was to minimize the adverse effects of transit stations on established neighborhoods. This objective was effected through the parallel efforts of local governments and MARTA (*5,7–10*). For their part, Fulton and DeKalb counties and the cities of Atlanta and Decatur implemented the following land-use planning guidelines affecting neighborhood stations:

- Midrise and high rise residential units were prohibited in the vicinity of neighborhood transit stations,
- Expansion of commercial uses was restricted to neighborhood-oriented activities in existing or proposed shopping nodes,
- Additional industrial use of the surrounding area was prohibited,
- Existing single-family residential zoning was continued, and
- Any future air rights development over the MARTA station, line segment, or parking lots was limited to necessary community facilities.

In the design of elevated transit stations, MARTA followed certain design principles:

- Extensive landscaping was included around the perimeter of stations and their parking lots, especially where station grounds were adjacent or near to residences. Landscaping was also included within the station groups to provide additional visual relief.
- Lighting, which is crucial for safety, was directed onto the station groups. Although stations would be highly visible, the glare or illumination of nearby residences would be avoided.
- Sound systems announcing train schedules can be disruptive. Speakers were therefore situated and designed to broadcast sound to the platforms and not into parking areas or toward nearby residences. This effort does not completely eliminate sound drift, but it does minimize it.
- Pedestrian and traffic flow to and from stations can adversely affect residences along access streets. Neighborhood stations were designed to have traffic routed away from pockets of residences where possible. This policy entailed constructing or reconstructing preferred access routes and directing traffic in such a manner that easiest access was achieved by bypassing most neighborhood streets.
- Rail sound was minimized through use of electrical guides and special track welding. It is almost impossible to hear a train from off the station grounds.
- Provision was made for onsite security personnel.

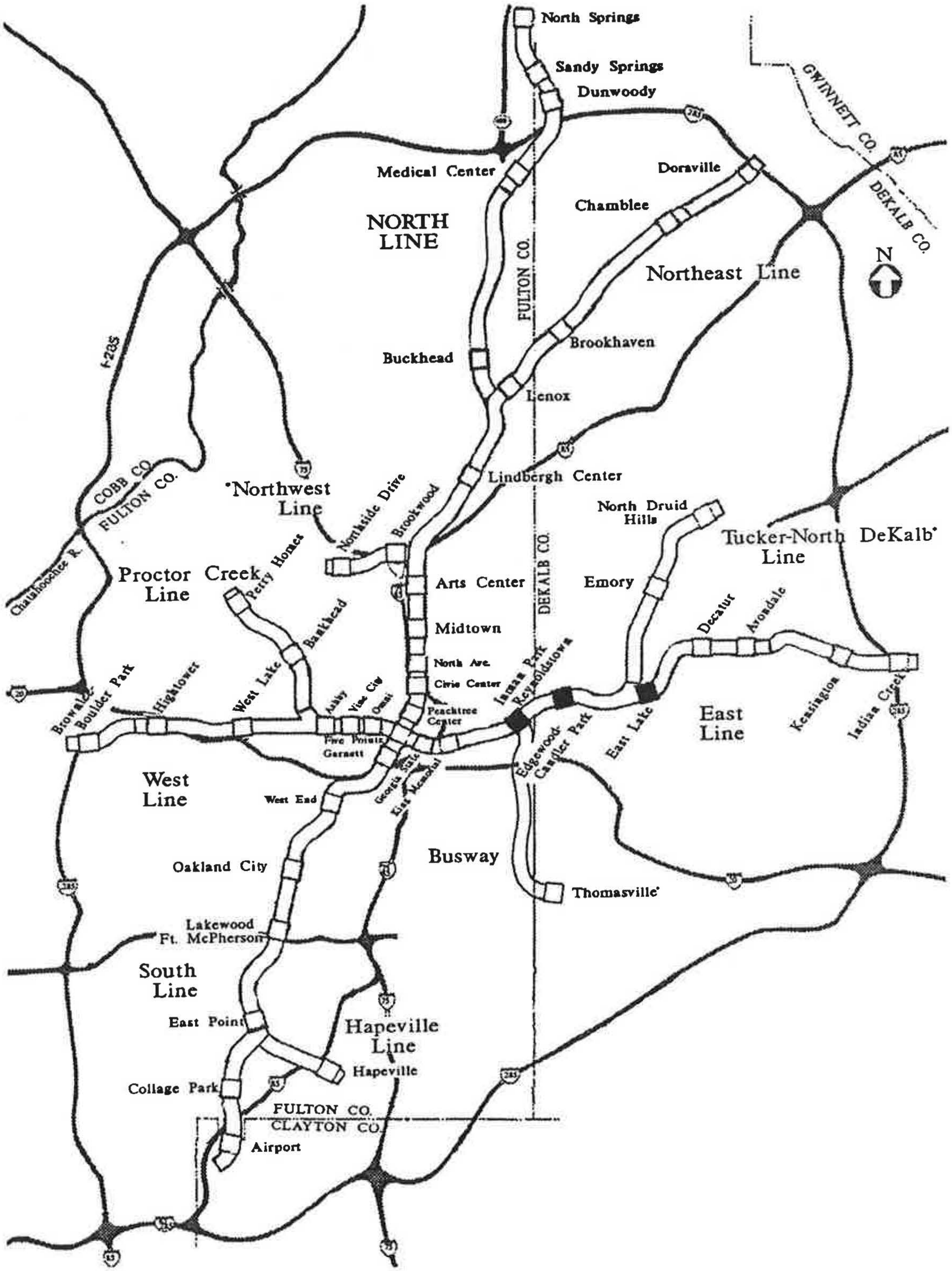

FIGURE 2 Area operator routes.

Major changes in land use or intensity because of the presence of the stations were not intended. Planning and zoning designations prevent higher-intensity land uses. Declining areas within stable neighborhoods were expected to be revitalized, because transit stations make neighborhoods more accessible and attractive (*11*).

Although it is MARTA policy to minimize the adverse impact of elevated transit stations in established neighborhoods of single-family homes, the effectiveness of this policy needs to be evaluated. The evaluation involves theory and model building, analysis, and interpretation. Theoretical considerations are posed first.

THEORETICAL IMPACTS OF ELEVATED TRANSIT STATIONS ON HOUSE VALUES

Transit stations improve the access of nearby residents to the CBD as well as other parts of the urban area served by such transit. Transit stations should thus influence urban residential values to rise in relation to station proximity (*12–19*). Commercial property value also rises with its proximity to transit stations (*18,20–23*). From a theoretical perspective, elevated transit stations should be associated with improvement of accessibility. Proximity of homes to these stations should be internalized in the market as a benefit in the manner shown by line R^a in Figure 3. That is, the closer the home is to a station, the higher its value.

Where elevated stations are associated with environmental disturbances imposed on nearby residents, residential values will fall in relation to station proximity. This is because nuisances such as noise, increased pedestrian and automobile traffic near the station, and the perceived accessibility of heterogeneous social groups to otherwise homogeneous neighborhoods will be internalized in the market as negative externalities (*24–27*).

Burkhardt (*28*) and Dornbusch (*29*) report that residential properties near Bay Area Rapid Transit stations (San Francisco region) suffered value decreases because of such nuisances. Baldassare et al. (*30*) report opinion survey research showing that where transit stations are elevated above residential areas, there is reduced preference for homes near those stations and the value of single-family homes presumably falls in relation to transit station proximity. In theoretical perspective, one may hypothesize that the distance from elevated neighborhood stations is associated with a declining single-family home sales price in the manner shown by line R^n in Figure 3. That is, the closer the home is to a station, the lower its value.

Which view is correct? Indeed, following Li and Brown (*31*), both may be correct. Li and Brown studied the nature of activities that generate both positive and negative influences at the neighborhood level. Positive and negative influences are collinear if they emanate from the same source in the same location and affect the same properties. Those influences vary across space perfectly and are thus unbundleable. The sign of the slope could be positive if home buyers viewed proximity as more benefit than nuisance, or the slope could be negative if buyers viewed proximity as more nuisance than benefit.

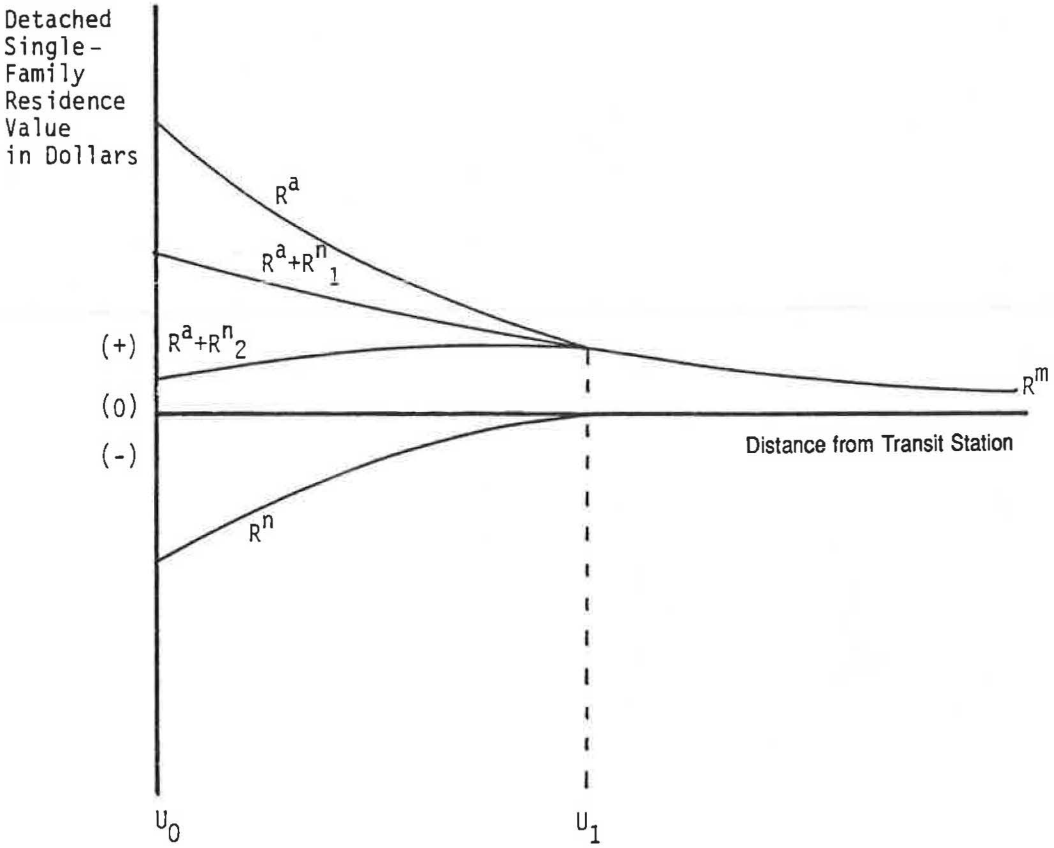

FIGURE 3 **Effect of residential heavy-rail transit stations on neighborhood residential property values.**

These twin possibilities are shown in Figure 3. If proximity to elevated transit stations was viewed more as a benefit than a nuisance, the revealed gradient would be the line $R^a + R^n_1$. That is, the nuisance influence of proximity, R^n, would be more than offset by the benefit influence of R^a. The slope would be positive but flatter than expected if there were no adverse value effects. On the other hand, if proximity was viewed more as a nuisance than a benefit, gradient $R^a + R^n_2$ would be revealed.

The individual beneficial or nuisance influences of elevated transit stations on single-family homes cannot be identified. Analysis can only reveal the observable gradient. However, whether on balance elevated transit stations of the sort planned and constructed by MARTA affect single-family home prices positively or negatively can be determined. Baldassare et al. (*30*) indicate the probability of a negative gradient. From Allen and Mudge (*12*), Boyce et al. (*13*), Davies (*14*), Davies (*15*), Langfield (*16*), Lee (*17*), and Spengler (*19*), a positive gradient appears likely.

The initial null hypothesis is that there is no significant influence of elevated neighborhood transit stations on single-family home values in adjacent neighborhoods. If that hypothesis is rejected, the alternate null hypothesis is that there is no significant and positive influence of elevated neighborhood transit stations on single-family home values in adjacent neighborhoods. If that hypothesis is rejected, the view of Baldassare et al. (*30*) is supported. If it is not rejected, the view of Allen and Mudge (*12*), Boyce et al. (*13*), Davies (*14*), Davies (*15*), Langfield (*16*), Lee (*17*), and Spengler (*19*) is supported.

STUDY AREA

The evaluation was applied to selected neighborhoods near elevated transit stations in DeKalb County. In particular, the evaluation was applied to the East Line of the MARTA system as it extends into DeKalb County (Figures 2 and 4). As

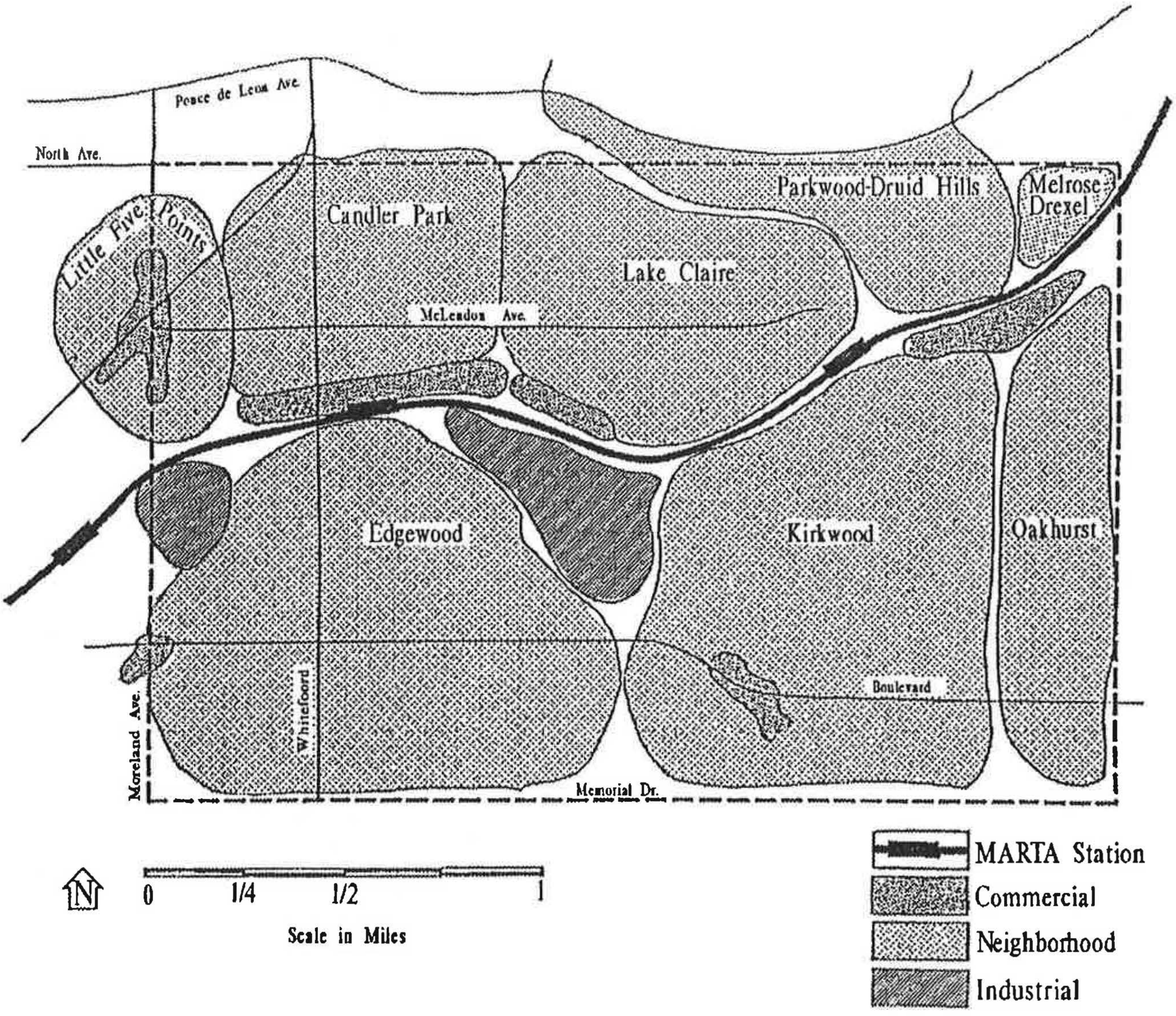

FIGURE 4 Study area neighborhoods.

Figure 4 shows, the study area is rectangular and measures approximately 2.7 mi east to west by 1.7 mi north to south. Arterials frame the area to the south (Memorial Drive) and east (Moreland Avenue). The northern boundary is a line from the intersection of Moreland and North avenues to Adair Park. The western boundary is a line from Adair Park to Memorial Drive. The entire study area is within DeKalb County. Roughly 80 percent of the study area is within the city of Atlanta, and 15 percent is within Decatur city limits. The remainder is in unincorporated DeKalb County. The study area contains six neighborhoods: Edgewood, Kirkwood, and Oakhurst south of the railroad corridor, and Candler Park, Lake Clair, and Melrose-Drexel to the north.

Of the 29 open transit stations (as of 1989), 9 are underground. Of the 20 surface and elevated stations, 13 are either designed to accommodate high-intensity development in their surrounding areas or set amidst commercial and industrial development away from single-family residences. Only 7 are designed for or set amidst primarily single-family homes. Of those, 2 are in south Atlanta and 2 are in west Atlanta. They are generally neighborhoods of transition. Only 3 elevated transit stations are along the same line, in sequence, and in stable neighborhoods dominated by single-family homes. Those are along the East Line. One station is just inside the Fulton County line, and the remaining two are between the county line and downtown Decatur, in DeKalb County. Unlike other parts of the system, the East Line neighborhood transit stations are not interrupted by stations that aim at serving nonneighborhood functions or that are otherwise amid nonresidential activity. Within the study area, the three closest transit stations are all neighborhood-oriented. This study area provides the largest uninterrupted segment of the system for analytical purposes.

The analysis was limited to this portion of DeKalb County for four additional reasons. First, these are among the oldest stations in the system. Some neighborhood transit stations (including those in northern DeKalb County) have only recently opened. There is concern that neighborhood markets near these new stations have not had time to fully internalize the influences of stations on home sale prices. The second reason was a matter of convenience. The property sale records of DeKalb County appeared to be better organized, more accessible, and more reliable on balance than the records of Fulton County. For example, although DeKalb County has instituted a geographic information system that incorporates property records, Fulton County has only recently engaged in such efforts. Third, the study area is relatively homogeneous in terms of housing stock age and household socioeconomic characteristics. This homogeneity allows relatively uncomplicated analysis of station influences. Fourth, the study area lent itself to manageability. No funds were available for this research. Rather, one graduate student spent 1 year collecting and analyzing data under the direction of a professor. The study area size afforded personal investigation and data collection on all 286 cases (house sales) used. It also generated a suitable number of cases on which to apply multivariate statistical analysis.

Even if sponsorship had allowed the inclusion of other neighborhoods near elevated transit stations, the analysis may not have been improved, largely because of the reasons cited earlier. The research design may be applied to those areas in the future, as the system matures and if sponsorship becomes available. This work clearly has potential limitations. The results reported here are at minimum a preliminary indication of the price effects of elevated neighborhood transit stations on single-family homes in adjacent neighborhoods. However, the results adequately address the question at hand and are generalizable to situations in which neighborhood-oriented, elevated transit stations are set amidst neighborhoods of single-family homes.

MODEL AND VARIABLE SPECIFICATION TAILORED TO THE STUDY AREA

A model of the theory can be expressed as

$$P_i = b_0 + b_1\mathbf{e}_i - b_2\text{TS}_i + w$$

where

b_0, b_1, b_2 = model coefficients;
P_i = the market price of transacted home i;
$\mathbf{e}_i$ = a vector of extraneous variables affecting each transacted home i;
TS_i = the value of distance of each transacted home i from a neighborhood transit station in 100-ft units; and
w = the stochastic disturbance.

The variation in detached single-family residential property prices with respect to transit station distance is of primary interest. The categories of attributes (the $\mathbf{e}_i$ term) are described in the following paragraphs.

Structural characteristics of a residential property are described by the square footage of both house and lot; the number of rooms; the number of stories; the presence of basement, foundation, enclosed porch (a market amenity idiosyncratic to Atlanta), garage, central air conditioning; and the age in years. A neighborhood identifier is included, because properties south of the rails are typically inside a city (Atlanta or Decatur) and populated by low- to moderate-income households, whereas homes north of the rails are typically outside a city and populated by households of moderate income. The two sides are otherwise similar in levels of crime, public education quality, and zoning.

Distance to the CBD is typically included in housing price equations as a gross measure of relative locational advantage (*31*). A CBD distance variable was not included in this study, however. The entire study area lies approximately 3 to 5 mi from downtown Atlanta, making differences between sites small. The travel time between stations within the study area is only 2 to 4 min.

Other variables considered important were zoning (whether a property was zoned for 8,500-ft^2 lots), whether the property was a corner lot, and whether the home was adjacent to a nonresidential property, such as a business. No homes were immediately adjacent to transit station property lines; few homes were actually adjacent to transit stations, although many were across a dividing street or intervening landscaping.

The data on 1986 sales of 286 single-family residences used in the empirical analysis were obtained from the DeKalb County tax assessor's office. For each case, this information included the sale price; the lot size; the square footage of the house; the number of stories; the number of rooms with windows; the presence (1) or absence (0) of a basement, foundation, garage, carport, central air conditioning, and enclosed porch; and the location south (1) or north (0) of the MARTA tracks (a proxy for neighborhood income status). The age of each house was expressed, such that the older the house the more likely it was to be renovated and desirable from a gentrification aspect. The price effect of corner lot status was also considered. The distance to the nearest MARTA station was expressed in 100-ft units. The quadratic expression of MARTA station distance was the square of distance. The quadratic specification allows the possibility of detecting convex or concave forms of the gradient.

Ordinary least squares regression was used. The double log specification was reported, except that the distance to MARTA stations was quadratic specification, age was linear, and noninterval relationships were binary (1,0). Other specifications did not perform as well. All specifications revealed similar relationships between the independent and the dependent attributes. All coefficients on attributes significant at the 0.05 level of the one-tailed *t*-test possessed the expected signs for this study area. Regression results are presented in Table 1.

TABLE 1 RESULTS OF LEAST SQUARES REGRESSION

Variable	Coefficient	*T*-Score
Lot size in square feet (log)	0.115357	2.768[a]
Age of house in years	0.002036	2.186[a]
Presence of basement (1 = Yes, 0 = No)	0.101579	3.050[a]
Presence of central air conditioning (1 = Yes, 0 = No)	0.168880	2.540[a]
Presence of enclosed porch (1 = Yes, 0 = No)	0.050358	1.45712
Presence of foundation (1 = Yes, 0 = No)	0.102184	2.43951[a]
Presence of garage (1 = Yes, 0 = No)	0.045808	1.05742
House size in heated square feet (log)	0.309196	3.62139[a]
Number of stories	0.122412	1.46621
Number of rooms (log)	0.289236	3.14346[a]
Location (1 = south of tracks, 0 = north of tracks)	−0.709327	18.33000[a]
Adjacent to commercial use (1 = Yes, 0 = No)	−0.009364	0.05358
Corner lot (1 = Yes, 0 = No)	−0.095314	2.13229[a]
Distance from nearest station (100-ft units)	−0.007077	1.89947[a]
Distance from nearest station squared (100-ft units)	0.000115	1.83069[a]
Constant	3.407924	
N	286	
Coefficient of determination	0.777	
Standard error of estimate	0.236975	
F-Ratio	62.563138	

[a]Significance at the 0.05 level of the one-tailed test.

RESULTS

All significant house attributes had the anticipated sign: house age, presence of a basement, presence of central air conditioning, presence of a house foundation, house size in heated square feet, and number of rooms. Nearly significant and possessing the expected sign was the presence of an enclosed porch. The presence of a garage was not significant; the mild climate, carports, and adequate street parking probably account for this. The positive sign for the age of housing stock indicates a preference for older homes. This was expected, because older homes are desirable throughout stable neighborhoods in Atlanta; gentrification has produced a level of renovation and modernization resulting in older homes being more modern than homes built in later eras.

The significant site attributes included lot size and corner status. Larger lots commanded a higher value, even at the margin. The local market preference was for greater space, and therefore privacy, within the rather narrow variation of lot sizes in the study area. Virtually no site can be subdivided, due to zoning restrictions. Corner lot status was not desirable, perhaps because corner lots were bounded by two streets and had smaller private yards than neighboring properties (because of double-street setback requirements).

Zoning (8,500- or 10,000-ft^2 minimum lot sizes) was not significant. This is not surprising in relatively homogeneously developed neighborhoods.

Although the coefficient on the binary variable indicating adjacency to nonresidential land uses was not significant, the coefficient had the correct sign.

Of primary interest was the fact that distance from the nearest MARTA station had a significant impact on property values. Within the neighborhoods studied, property value increased in relation to proximity to a MARTA station. The first null hypothesis, that there is no significant association between home values and transit station proximity, was rejected. The alternative hypothesis, that there is no positive association between house value and station proximity, was not rejected. (The quadratic term was also significant and possessed the correct sign.)

The regression equation was also run separately for cases within ½ mi (179 cases) and beyond ½ mi (107 cases) of the nearest MARTA station (not reported here). The performance of the distance-to-station variables was ambiguous; that is, coefficients were not significant although signs were consistent with signs from the previously described regression. Such weak performance cannot be explained except that other house attributes are really more influential in predicting price than proximity to MARTA stations. In fact, the coefficients from the first regression are rather small and really do not influence price substantially (albeit significantly) relative to other attributes.

SUMMARY

Whether the revealed gradient of house value in relation to elevated transit station proximity incorporates both beneficial and nuisance influences cannot be determined for reasons explained by Li and Brown (*31*). However, these results support the view expressed by Allen and Mudge (*12*), Boyce et al. (*13*), Davies (*14*), Davies (*15*), Langfield (*16*), Lee (*17*), and Spengler (*19*), that transit station proximity is beneficial to residential values. The results contradict inferences by Baldessare et al. (*30*) that elevated transit stations may adversely affect property values. On the other hand, this study was based on behavior revealed in home sales, whereas Baldessare et al. (*30*) relied on opinion survey research.

Yet, Baldessare et al. (*30*) may be perfectly correct in their inference that when such stations are not located and designed with sensitivity to surrounding neighborhoods, the market will reveal adverse price effects on homes. Indeed, MARTA's second round of planning included considerable design attention directed at minimizing adverse effects. Sensitivity to the impact of elevated stations on established neighborhoods was ensured because of citizen participation in the planning and design process. Ignoring citizen concerns delayed MARTA construction until those concerns were reasonably satisfied. The lessons learned should be obvious.

At minimum, design features used by MARTA should be considered by other rapid-rail planners who are concerned about extending elevated transit stations into established neighborhoods where the intent of those stations is to serve neighborhoods rather than accommodate higher-intensity activities.

Despite the analytical limitations of this research, the results and insights are generalizable to other areas of the country now engaging in rapid-rail transit that include elevated transit stations. More research is needed to determine the extent to which specific locational, design, and participatory features of a rapid-rail planning process minimize adverse effects and maximize beneficial effects. This study is but a building block in those future efforts.

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Case Study in Land Use and Parking Regulations in Support of Campus Transit Services: Development of CY–RIDE in Ames, Iowa

ROBERT T. BOURNE AND PETER SCHAUER

The continued successful provision of fixed-route and demand-responsive transit service on the Iowa State University campus and throughout the city of Ames has been the result of cooperation between the city of Ames, the university administration, and the university students. These three groups have recognized the relationship between land use, parking, and transit. In 1981, when CY–RIDE was in its formative stage, they agreed to reduce available parking and increase available transit services. Although no master development plan spells out a formal policy of substituting transit service for parking, through innovative parking policies and aggressive (high-density) land use the transit service has become indispensable for the mobility of Ames citizens and especially Iowa State University students. The development of the transit service is traced from a political standpoint and the creation of innovative parking policies is emphasized as the operational key to a strong transit service. The strength of the CY–RIDE service is demonstrated by excellent operating statistics such as 36.5 passengers per revenue-hour, 3.1 passengers per revenue-mile, and 53 rides per capita per year. Aggressive land use and innovative parking policies are only partial factors in building a strong transit service; the actual management and approach to operations (which involves students) are the final links in a successful campus transit service.

The Ames Transit Agency (operating as CY–RIDE) is the municipally owned bus system that provides transit service in Ames, Iowa. It is an agency of the city that has members of the Iowa State University (ISU) administration and the government of the student body (GSB), as well as city representatives, on the transit board. The original CY–RIDE service was created in 1975, following the termination of privately owned bus service in Ames. CY–RIDE is an abbreviation of Cyclone-Ride. Cy is also the name of the ISU mascot, and ISU athletic teams are known as "Cyclones." The Ames Transit Agency was created in 1981 to improve transit services.

A need for an expanded and improved bus service was apparent in the late 1970s. CY–RIDE was started, reluctantly, by the city of Ames to provide a minimal level of transit service. The original service in 1975 was solely a dial-a-ride system that gradually evolved to a hybrid system of fixed routes in certain parts of town and dial-a-ride in other parts of town.

During the time that the fledgling transit system was struggling, ISU enrollment was increasing. As the enrollment increased, complaints regarding parking on campus became a chronic problem. Complaints from students who did not own cars centered around the poor service provided by CY–RIDE and the lack of evening and Sunday service. The ISU administration was interested in finding alternatives to the cost of constructing and maintaining parking spaces, whereas the students were primarily concerned about poor transit service. The city's primary concern was the escalating cost of transit service and the negative comments that the city had received about the existing service.

The spark that ignited and expanded CY–RIDE service was the widely held belief by students that improved mobility was required for a full and complete life on campus. The existing CY–RIDE system did not meet that need. The ISU administration was approached by and cooperated with the students in exploring other student-run or student-supported transit systems in the Midwest.

From this spark of interest, the mayor of Ames formed a citizen's committee in 1979 to investigate alternatives and improvements to the CY–RIDE service. Although the city of Ames and ISU had had successful joint projects such as water, electric, and fire services, there was concern about the possible changes and directions of a transit authority. Both parties were concerned about who would establish routes, fares, and the structure of the board of trustees of any organization that would control the operations and finances of the transit service. The city was concerned about the total cost of an expanded level of service. Concerns about the joint project were further complicated by student interest as represented by the GSB. The GSB was particularly concerned about the day-to-day operations of expanded service and the decision-making (management) structure. Service levels were a primary concern of the student body in general, as well as routes, fares, and the structure of the board of trustees.

After 18 months of negotiations between the city, ISU, the GSB, and several concerned citizens, the Ames Transit Agency was formed. The purpose of the agency was to undertake the establishment, acquisition, operation, management, control, and governance of transit services in and for the city of Ames.

The creation of the agency in 1981 alleviated some of the city's concerns about escalating costs of service, because the financial contribution from the university and the students

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was substantial. The agency immediately planned to provide more service for students, thus resolving many of the GSB concerns. ISU was cautiously optimistic about the agency and hoped that in the long term it would help resolve some of the parking issues on campus. The cooperation between these three diverse groups—students, university, and city—was remarkable. It was so remarkable that the resultant transit agency was the basis of the city of Ames' receiving the all-American city award in 1983 from the National League of Cities.

SERVICE PRODUCTIVITY AND OPERATING CHARACTERISTICS

During the first years of the Ames Transit Agency, ridership grew rapidly. The fare for students was lowered from $0.50 to $0.25. The dial-a-ride fare was increased from $0.75 to $1.25. Two new routes were added in August 1981, and evening and Sunday service was initiated on a limited basis. The response to these service changes was excellent. Ridership increased from 331,365 to 902,711 passengers in 1 year and continued to increase in following years. In 1982–1983, ridership increased to 1,212,800 and in 1983–1984, ridership totaled 2,100,029. By 1988–1989, it had stabilized at 2,456,000 (Figure 1).

As the service improved, demand increased and the service was increased proportionally. Ridership standards were adopted to determine when service should be added or reduced. In 1983–1984, service on the three primary routes was increased from a 30-min interval to a 20-min interval. This made service extremely convenient for students going to and from classes. (With a 20-min interval, buses are able to arrive on campus a few minutes before classes start and also a few minutes after classes end. This convenience makes it possible for students to make several trips per day to and from campus, such as when they have a 2- or 3-hour break between classes.)

To secure a strong financial base, the three local funders—city, university, and students—attempted to provide adequate local funding in an effort to remain as independent of state and federal funds for operations as possible. During the early 1980s, the continuous message from UMTA and other administration officials was that transit subsidies would be substantially reduced or eliminated. However, the reality was that federal operating assistance increased from $54,639 in 1981–1982 to $219,812 in FY 1989. Operating assistance from the Iowa Department of Transportation was relatively stable during that time, fluctuating between $70,050 and $101,255, but it increased to $154,461 in FY 1989. Local contributions in the form of farebox revenue from the passengers, city tax levy, a mandatory student fee assessment from the GSB, and an ISU administration contribution provided adequate funding for operations. Local funding as a percent of operating costs varied from 129 percent in 1981–1982 to 88.2 percent in 1989–1990. Figure 2 shows the percentage of local funding to operating expenses. Figure 3 shows the sources and percentage of all revenue.

Productivity also increased during this time of expansion. In FY 1981 (Figure 4), productivity on the city-run CY–RIDE service was 15.9 passengers per revenue-hour. This increased to a maximum of 39.8 in FY 1985 and then stabilized at 36.5 passengers per revenue-hour in FY 1989. The reduction in passengers per revenue-hour is a reflection of the additional services that have been added.

The CY–RIDE service concept is to provide a convenient alternative to the automobile while maintaining control of service costs. Service is provided from 6:00 a.m. until approximately 12:45 a.m. on weekdays. Saturday service starts at 7:00 a.m., and Sunday service starts at 9:00 a.m. Friday and Saturday evening fixed-route service ends at 10:45 p.m. This is supplemented by Night Ride, which is a demand-responsive service that operates until approximately 2:30 a.m. The primary purpose of this service is to return inebriated students

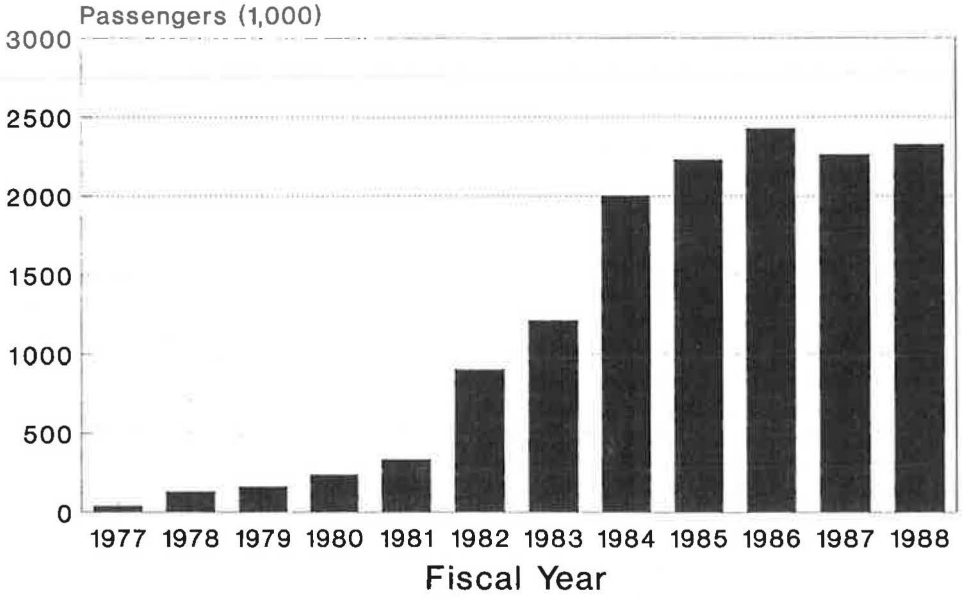

FIGURE 1 Ridership totals for FY 1977–1988.

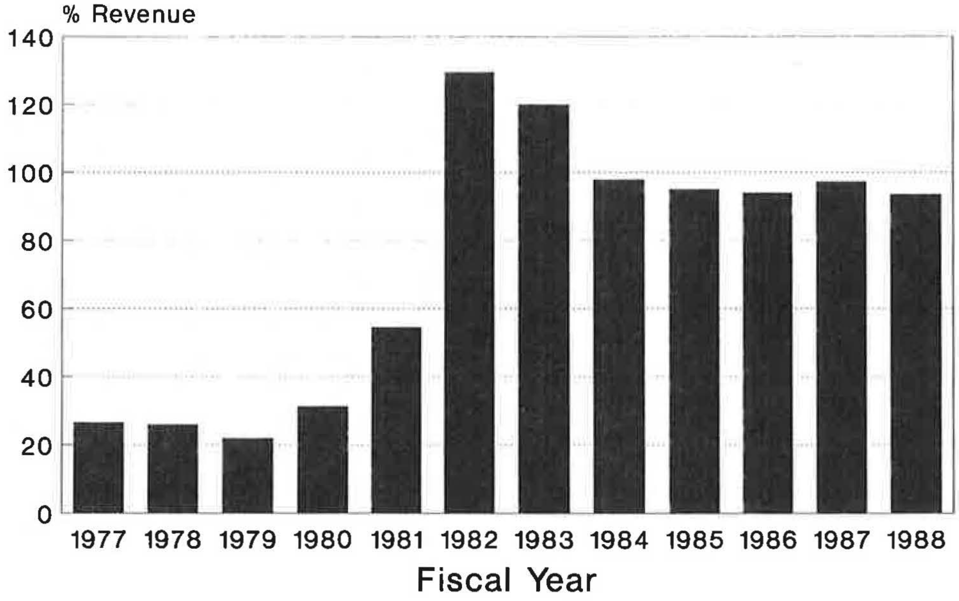

FIGURE 2 Local revenue/operating expenses for FY 1977–1988.

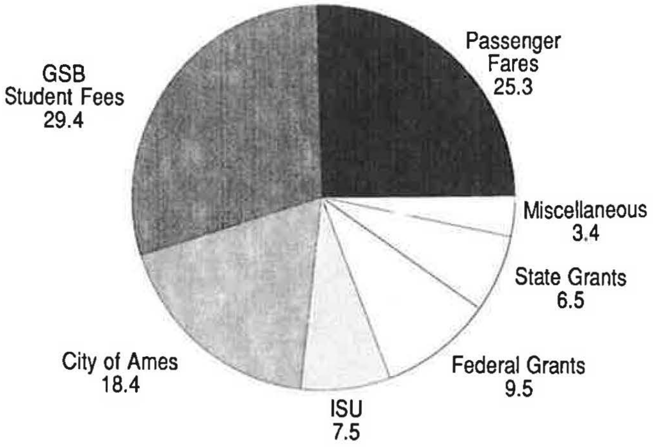

FIGURE 3 Sources of all revenue for FY 1990.

to their residences. Sunday fixed-route service ends at 11:45 p.m.

Service is convenient, frequent, and reliable. The spatial development pattern of Ames lends itself to relatively long travel distances for a small community along a few major corridors. This pattern makes a bus service extremely attractive, because many of the outlying apartment buildings are beyond a comfortable walking distance from the ISU central campus. By providing frequent service during the day at 20-min intervals and a reasonable evening service at 40-min intervals, CY–RIDE is competitive with walking and bicycling. It is also more time-efficient than driving, because of the lack of parking spaces on campus.

UNIVERSITY PARKING POLICIES AND LAND USE

As CY–RIDE became established and became an effective and dependable component of the community, ISU made several critical decisions regarding land use on its central campus that impacted the transit service. First, it had been the desire of the ISU administration to keep the central campus free of automobiles. Traffic gates were installed in 1976 to regulate the flow of traffic through campus. Second, as a result of the early successes of the system and the need to construct additional buildings on campus, the ISU administration consciously began to reduce the number of available parking spaces.

Since 1983, six new or expanded buildings have added 869,566 ft^2 of building space on ISU's central campus (Figure 5). More than 500 parking spaces have been eliminated from the central campus because of the new buildings. The additional work and education activities generated by this construction boom have created a demand for more than 1,000 additional parking spaces. However, these 1,000 spaces were not constructed. Some additional peripheral parking was constructed on the west edge of campus, but many people who choose to drive must walk more than 1 mi to their worksite. The elimination of parking combined with the building additions further aggravated the parking problem.

At the same time that parking was being eliminated, the ISU administration, through the parking systems office, began funding a shuttle bus from the parking lots located between the football and basketball stadiums. This is a 5,000-stall surface parking lot. It is used primarily for events at the Iowa State Center and during home football games. This lot covers a large area and is only used to capacity approximately 30 days per year for football and basketball games and rock concerts. The university felt that this was an inefficient use of the space and provided a free shuttle bus. Many of the off-campus students, as well as faculty and staff, used the shuttle bus to get to their classes or workplaces and thereby satisfied the desire of the university for more efficient use of the lot.

The shuttle provides a 6- to 10-min ride to most of the on-campus classroom buildings and operates at a 7-min interval during rush hours and at 15-min intervals during the midday. Approximately 1,700 passengers per day are carried on the

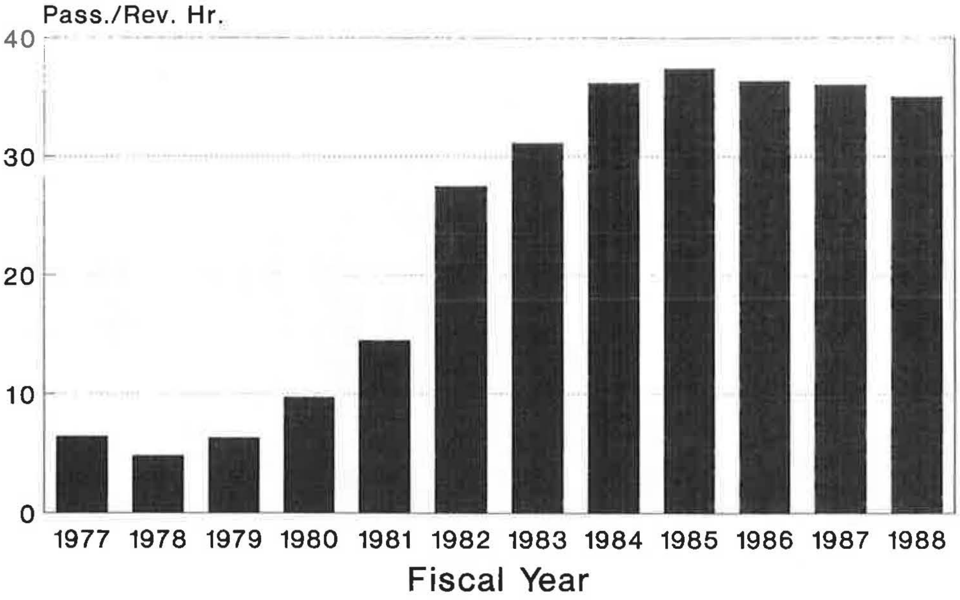

FIGURE 4 Passengers per revenue hour for FY 1977–1988.

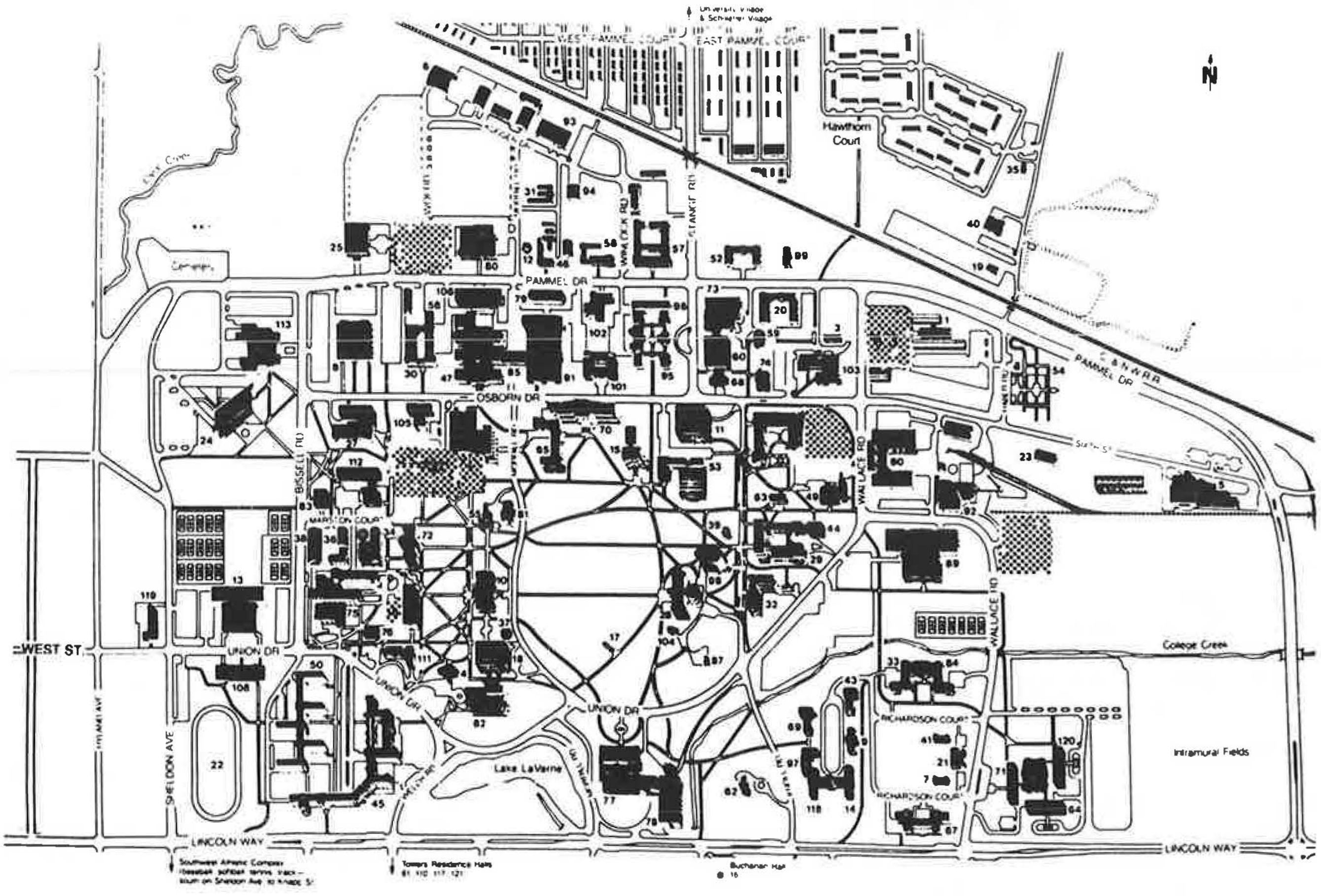

FIGURE 5 Iowa State University main campus.

shuttle service, thus eliminating the need for approximately 850 parking spaces on the central campus. The cost of this service is approximately $44,000 per year. Although the university established the shuttle service and was eliminating parking spaces, fees for parking were also increased. The public ramp at the Memorial Union Building gradually increased its fees, and the university increased the fees for reserved parking. Fees that were only $30 per semester in 1983 are now $120 per semester.

The rapid growth of the system in the first 2 years proved to the ISU administration that CY–RIDE was capable of moving large numbers of people to the central campus safely and efficiently. The university had taken a conservative, watchful approach to the new transit system. Following its initial successes, the university made several additional changes in parking regulations.

In 1983, additional restrictions were placed on students who lived in Ames and owned an automobile. They had been permitted to hunt for parking spaces on campus. That is, more permits were issued than parking spaces were available. The university assumed that there would be a turnover of spaces so that the maximum number of spaces needed would always be less than the number of spaces available. This caused many complaints, as students would often spend 15 to 20 min looking for a space. To correct this complaint, the parking shuttle from the 5,000-stall Iowa State Center parking lot to the central campus provides an adequate number of spaces with a minimal amount of time spent looking for a space. (Minimal time is spent if drivers are wise enough to make the voluntary decision of parking in the 5,000-stall parking lot.)

On-campus parking permits were further linked to the bus service in a unique way. If a student lived in an apartment or house near (within four blocks of) a CY–RIDE fixed route, they were not eligible to receive a parking permit for the central campus. Only students living in surrounding towns or in the few apartment units that were not served by CY–RIDE fixed-route service were able to receive parking permits. This policy increased the demand for CY–RIDE service, and ridership continued to increase to 2,427,124 by 1985–1986. Following this change in parking regulations, apartment owners became extremely concerned about the proximity of their units to CY–RIDE service. CY–RIDE has become a major selling point for rental units and is advertised in most newspaper ads for units that are near a CY–RIDE route. (Several owners are offering a discounted or free semester pass to encourage use of CY–RIDE and to maximize their unit rental.)

The physical land-use changes that the university implemented and the more restrictive parking policies were further complemented by a more aggressive enforcement of parking regulations. Parking violation fees were increased, chronic violators were towed, and in 1987 over 66,000 parking violations were issued by the parking system office. In 1988, 88,000 parking violations were issued. The increase in parking fees, as well as the increase in ticket revenue and the reduction in parking spaces, have made the parking system at ISU self-sufficient, because the fees and penalties generate enough revenue to cover the cost of parking maintenance and capitalization.

The net result of CY–RIDE service has been an intensive academic use of the existing central campus. The central campus is primarily a pedestrian campus, open only to CY–RIDE buses or ISU maintenance vehicles. Academic interaction, which is one of the primary functions of the university, has been enhanced by the close spacing of buildings allowed by minimized central campus parking. Finally, the visual attractiveness of the central campus is enhanced by the lack of automobiles, traffic congestion, and large expanses of parking lots.

There has also been a change in attitude toward automobile use and ownership. Students have a heightened awareness that the transit service is affordable and efficient and meets their mobility needs to and from campus, as well as circulating through the city of Ames. Many students realize that they do not need a car. This point is especially important to those who are on limited budgets. Promotional efforts and advertising aimed at students and their parents emphasize that a car is not necessary while attending ISU.

FINANCIAL BENEFITS

The city has been satisfied with the service provided by CY–RIDE and the changes that have occurred. Complaints about poor public transit service have been eliminated. With the capitalization of the service through the purchase of new buses and construction of a maintenance facility, service reliability has improved and been noted by city officials, riders, and nonriders. The city has been able to fund CY–RIDE within the $0.54 per $1,000 limit of assessed valuation imposed by Iowa law. Figure 6 shows the city tax rate during the history of CY–RIDE operations.

In many respects, ISU has been the principal financial beneficiary of the CY–RIDE service. On-campus parking spaces and the concurrent maintenance costs have been reduced. The university has also been able to implement an aggressive land-use policy that allows higher-density activity on the central campus. The university is using its existing parking lot more fully than would be possible without a bus service. Academic interaction is enhanced by the proximity of buildings while an extremely attractive central campus is maintained in a parklike setting.

The ISU contribution has been less than the cost of additional parking by a factor of almost five to one. A total of 500 spaces have been eliminated, and the construction of 1,000 has been avoided. ISU calculates a $500 maintenance and capitalization cost per parking space per year. At $500 per space, ISU has saved $750,000 per year while contributing $160,000 to the transit agency, a net savings of $590,000. The university is also able to use the bus service as an inducement for students who may need financial relief and cannot afford the cost of operating an automobile.

The students also benefit financially from a low-fare ($0.25) bus system. Their satisfaction with the service can be inferred from the lack of complaints about the level of service. It is estimated that 85 percent of the students living in off-campus housing and 25 percent of the students living on campus have ridden CY–RIDE at some time during their college career and with few complaints. On the basis of ridership analysis, 25 percent of the student body depends on CY–RIDE for daily transportation. To ensure that the students' needs are voiced, two student transit board members, who are appointed yearly, have been an effective force in improving service and

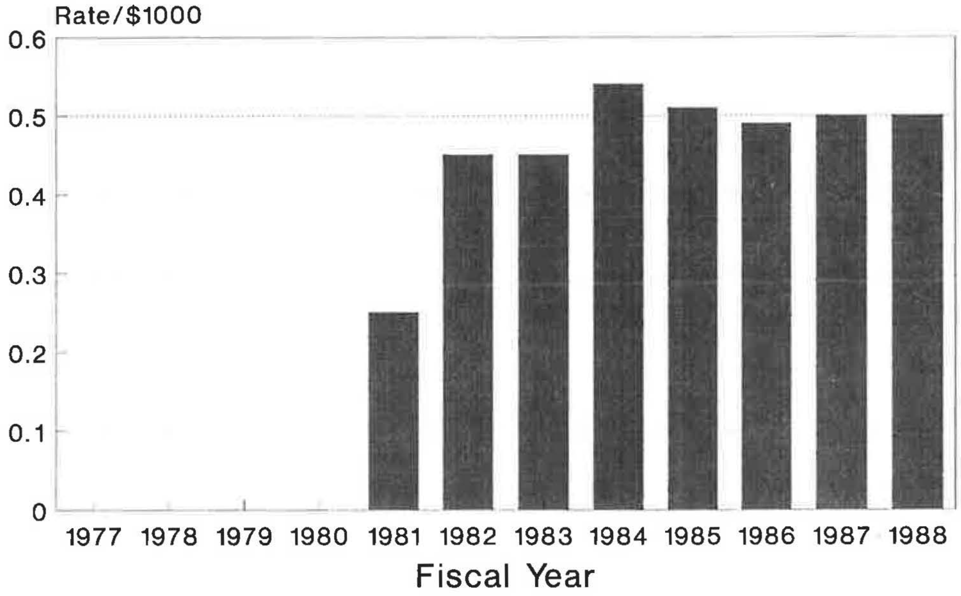

FIGURE 6 Tax levy rate per $1,000 for FY 1977–1988.

negotiating additional local funding through the university, the city, and student fees. Their participation has been one of the cornerstones of the success of CY–RIDE service and has created a strong financial base through student fee assessment.

CONCLUSION

CY–RIDE service in Ames has allowed more changes in land use than are typical in an automobile-based environment. ISU has been able to change the land-use patterns on its central campus and maintain a high quality of campus life for its nearly 25,000 students. Travel patterns have changed accordingly, and mobility is excellent despite the high-density activity level of the central campus.

There is a marriage between land use and the management of the transit system. The success of the system stems from the consumer-based service that CY–RIDE provides. The ISU administration waited cautiously for 2 years to see if CY–RIDE would be successful before deciding to assist with the changes that transit managers desired in the physical makeup of the campus and parking regulations. University officials implemented aggressive building and parking policies only when they became confident that CY–RIDE could deliver the service needed. The positive political support from the city, the university, and the students, through the effective composition of the transit board, has provided the necessary good will from each entity to make the service a strong community asset. The staff of CY–RIDE recognizes the mandate to provide high-quality service that is demanded from the three parties represented on the transit board. The high-quality service provided by the staff then influences the decisions made by the three parties for actions that encourage transit use, thereby completing the cycle of a model land-use and parking program that supports transit.

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PART 4

Bus Operations

Bus Service Times and Capacities in Manhattan

LEO F. MARSHALL, HERBERT S. LEVINSON, LAWRENCE C. LENNON, AND JERRY CHENG

Bus dwell times, passenger service times, and bus capacities are analyzed for the Midtown Manhattan Central Business District. Surveys were conducted in 1988 at seven sites on Madison, Fifth, and Sixth Avenues. Service times per passenger averaged approximately 8 sec as a result of complex fare structures. Dwell times were best predicted by an exponential model that explained more than two-thirds of the variance. Application of the *Highway Capacity Manual* formula for the capacity of a bus stop produced acceptable results in cases for which the lane was used exclusively by buses. More significantly, the reductive factor of 0.83, as given in the *Highway Capacity Manual*, was found to closely approximate the reductive effects of buses on the capacity of Midtown Manhattan streets.

The New York City Department of City Planning (DCP) has been updating its methodology for evaluating the capacity impacts of express buses in Midtown Manhattan. Accordingly, in 1988, DCP commenced a study to verify and update the passenger car equivalent (PCE) values used in its analysis. As the study progressed, it became apparent that new approaches were necessary, and that answers were needed to questions such as the following:

- How do fare collection policies affect passenger service times?
- How do the values of the reductive factor *R* compare with those given in the 1985 *Highway Capacity Manual (HCM)* (*1*)?
- How well do *HCM* (*1*) methodologies estimate the capacities of bus stops?

To address these questions, the available literature on dwell times and bus capacities was reviewed. Special field studies were made of bus performance on Midtown Manhattan avenues, and suggested capacity guidelines were developed. This paper presents the results of these surveys and analyses.

BACKGROUND

The HCM (*1*) presents methodologies for use in the analysis of the capacity and level of service of various types of roadways. Each specific analysis begins with the assumption of certain ideal conditions and then utilizes adjustment factors to reflect actual conditions. The ideal of primary importance here is that all vehicles operating in a traffic stream are passenger cars. This assumption is, of course, routinely violated in large urban areas such as New York City.

To allow for this, the *HCM* (*1*) uses the concept of passenger car equivalent (PCE), defined as "the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing traffic, roadway, and control conditions." It is assumed that any heavy vehicle will have the same impact on the capacity and level of service of a segment as the equivalent number of passenger cars. The PCE of any heavy vehicle is not a fixed number but rather a function of prevailing conditions.

The *HCM* (*1*) gives the value of 1.5 as the PCE of a through bus (i.e., a bus operating, usually on an urban arterial, without stopping to receive or discharge passengers); in other words, such a bus is assumed to be equivalent in traffic impact to approximately 1.5 cars. Techniques are presented for estimating the PCE of a bus whose passenger service activity impedes the flow of other traffic, on the basis of signal phasing, stop duration, and average vehicle headway. This methodology, which incorporates nationwide averages, is summarized in the *HCM*'s Table 12–8 and the equation accompanying it (*1*).

LITERATURE SEARCH

Prior research into bus operations and their effects on traffic has focused not on bus PCEs but on the dwell times of buses operating on both local and suburban routes. Factors contributing to dwell time include the configuration and occupancy of the bus, the number of boarding and alighting passengers, the frequency of stops, and the method of fare collection (*1*).

Hoey and Levinson (*2*) reported boarding times ranging from 2 to 8 sec per passenger according to the fare collection mechanism used. Specific boarding times per passenger were observed to be approximately 2.0 sec when the fare was either prepaid (in the form of a pass), postpaid (i.e., paid on leaving the bus), or nonexistent; 2.6 to 3.0 sec when fares were paid with a single coin; 3.0 to 4.0 sec for multicoin fares; and 6.0 to 8.0 sec when paper currency was involved. The large disparity associated with paper currency stems in part from the use of bill-taking fareboxes, which tend to jam (*3*), and in part from the practice of having drivers handle cash fares, make change, and give refunds.

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To highlight factors other than fare collection, Zografos and Levinson (*4*) examined dwell times for a no-fare transit system. The most important of these other factors were the number of boarding passengers and the number of passengers already aboard. Indeed, the average time of 2.0 sec per passenger was found to apply primarily when relatively few persons boarded a relatively uncrowded bus.

The number of boarding passengers is also addressed by Guenthner and Sinha (*5*), who developed a marginally acceptable ($R^2 = 0.36$) logarithmic model (presented here with notation changed):

$$P = 5.0 - 1.2(\ln N) \quad (1)$$

where

P = dwell time per passenger, and
N = total number of boarding and alighting passengers.

Other factors cited as possibly relevant include the existence of structured or multicoin fares, the use of single-door buses, the presence of passengers with special needs, and the distribution of stops.

Levinson (*6*) presents a thorough analysis of travel times as they relate to bus speeds, dwell times, stop frequency, and bus acceleration. He finds average dwell times of approximately 16 sec for heavily patronized suburban routes (similar to the type considered by DCP) and 50 to 60 sec at very busy central business district (CBD) boarding points.

The *HCM* (*1*) reviews all of the foregoing and suggests boarding times of 2.6 sec per passenger for single-coin fares, 3.0 sec for exact multicoin fares, and 3.5 sec for exact fares when standees are present.

DATA COLLECTION

Field reconnaissance investigations were conducted to observe express bus operations and bus priority treatments on Madison, Fifth, and Sixth avenues. Three priority treatments are in effect: a double-width exclusive bus lane (XBL) for buses only on Madison Avenue (with right turns prohibited); a two-lane red zone on Fifth Avenue for buses and right turns; and a single-lane red zone on Sixth Avenue for buses and right turns. Of these treatments, the two-lane red zone was found to be the most effective.

Seven midtown express bus stops were studied. Each stop is a major boarding point for the operator(s) serving it or is an area susceptible to traffic problems:

1. Madison Avenue from 44th to 45th Street,
2. Madison Avenue from 46th to 47th Street,
3. Fifth Avenue at 48th Street,
4. Fifth Avenue from 43rd to 42nd Street,
5. Fifth Avenue from 41st to 40th Street,
6. Sixth Avenue from 43rd to 44th Street, and
7. Sixth Avenue from 44th to 45th Street.

Each site was surveyed over three consecutive days (a Tuesday, a Wednesday, and a Thursday) between 4:30 and 5:30 p.m. Altogether, 449 buses were counted, representing 68 routes operated by 14 carriers. The following factors were included in the survey:

- Dwell times included the passenger service time plus the time needed to open and close the doors.
- Passengers were counted as they boarded each bus. Because these were peak-hour express routes, there were no alightings. Any passenger who disembarked after learning that he had boarded the wrong bus was considered to have been served, and was therefore counted. On the other hand, straggling passengers, for whom the doors were reopened after the bus had begun to leave the stop, were not counted.
- Three methods of fare collection were observed: (a) coin-only fareboxes, which require the exact fare in any combination of subway tokens or coins; (b) coin-and-bill fareboxes, which accept subway tokens, coins, and dollar bills; and (c) payment of the fare directly to the driver, who will change any bill up to $20. The coin-and-bill fareboxes, as well as the New York City Transit Authority's coin-only fareboxes, are electronic. For the purposes of this analysis, these fare collection procedures were combined into a single indicator variable, BILLS, which took values of 1 if bills were accepted and 0 otherwise.
- Three causes of bus operation-related delays were noted: (a) bus held for schedule adjustment; (b) queue of buses serving the same or adjacent stop; and (c) straggling passengers being served. An indicator variable B in the dwell time analysis accounted for the presence of such delays.
- Three cases of delay attributable to general traffic conditions were noted: (a) red lights; (b) right turns into a side street; and (c) overall congestion. The first two tended to occur at near-side bus stops. An indicator variable T in the dwell time analysis accounted for the presence of these delays.

In addition, traffic counts were conducted at all bus stops in question and at the intersections immediately beyond them. These counts provided a basis for comparisons of bus and car volumes at each site. For each vehicle using the curb lane, information was collected pertaining to type (e.g., automobile), function (e.g., taxi), and actual activity (e.g., stopping to discharge a rider). Also noted was activity belonging at the curb (such as passengers boarding a bus) but occurring in the moving lanes. Intersection counts were more traditional in scope: vehicles entering the intersection in each lane were classified by type. Tables 1 and 2 present the peak-hour bus and passenger car flows observed in the curb and second lanes.

DWELL TIME ANALYSIS

Bus dwell times and passenger service times obtained from the various surveys are presented in Tables 3 and 4. These tables show the means, standard deviations, and coefficients of variation by survey site and method of fare collection, respectively.

In apparent violation of prior research findings, average dwell time per passenger ranged from a low of 5.52 sec at Site 6, where only coins were taken, to a high of 9.22 at Site 7, where bills were accepted. Also, the service times averaged 6.13 sec per passenger on coin-only buses and 8.55 sec on coin-and-bill buses. The *HCM* (*1*), Table 12–9, gives a range of 6 to 9 sec for complex cash fares.

It should be noted that the standard deviations presented in Table 2 are very close to one another, indicating that a change in fare collection policy would simply shift the

TABLE 1 PEAK-HOUR CURB LANE FLOW RATES BY CORRIDOR AND VEHICLE CLASSIFICATION

SITE*		BUSES per hour	CARS per hour	TRUCKS per hour	TOTAL per hour
#1	Madison Av/44-45 St	34	6	1	41
#2	Madison Av/46-47 St	45	1	0	46
#3	Fifth Av/48 St	36	24	0	60
#4	Fifth Av/43-42 St	48	10	4	62
#6	Sixth Av/43-44 St	18	98	10	126
#7	Sixth Av/44-45 St	14	19	3	36

* Volumes recorded at site #5 are unreliable due to construction at 41st Street.

TABLE 2 PEAK-HOUR SECOND-LANE FLOW RATES BY CORRIDOR AND VEHICLE CLASSIFICATION

SITE*		BUSES per hour	CARS per hour	TRUCKS per hour	TOTAL per hour
#1	Madison Av/44-45 St	112	152	28	292
#2	Madison Av/46-47 St	128	44	8	180
#3	Fifth Av/48 St	160	180	40	380
#4	Fifth Av/43-42 St	128	244	20	392
#6	Sixth Av/43-44 St	84	320	56	460
#7	Sixth Av/44-45 St	84	340	52	476

* Volumes recorded at site #5 are unreliable due to construction at 41st Street.

TABLE 3 SUMMARY OF EXPRESS BUS DWELL TIME DATA BY SITE FOR THREE TYPICAL FALL BUSINESS DAYS, 4:30 TO 5:30 p.m.

SITE NUMBER AND LOCATION [number of buses surveyed]		DWELL TIME (seconds)	NUMBER of PASSENGERS	DWELL TIME per PASSENGER (seconds)
1. MADISON AVENUE	mean	123.58	13.85	9.08
44TH-45TH STREETS	std dev	109.41	7.47	5.59
[94 buses]	c.v.	0.89	0.54	0.62
2. MADISON AVENUE	mean	52.39	8.36	6.60
46TH-47TH STREETS	std dev	33.59	4.31	3.61
[58 buses]	c.v.	0.64	0.52	0.55
3. FIFTH AVENUE	mean	84.08	9.43	9.15
48TH STREET	std dev	50.09	4.72	2.84
[37 buses]	c.v.	0.60	0.50	0.31
4. FIFTH AVENUE	mean	44.04	7.65	7.15
43RD-42ND STREETS	std dev	36.24	5.88	5.01
[83 buses]	c.v.	0.82	0.77	0.70
5. FIFTH AVENUE	mean	25.56	5.28	6.08
41ST-40TH STREETS	std dev	15.75	3.73	5.05
[80 buses]	c.v.	0.62	0.71	0.83
6. SIXTH AVENUE	mean	32.94	6.31	5.52
43RD-44TH STREETS	std dev	14.63	3.01	4.28
[35 buses]	c.v.	0.44	0.48	0.78
7. SIXTH AVENUE	mean	50.81	5.77	9.22
44TH-45TH STREETS	std dev	36.54	3.61	5.35
[62 buses]	c.v.	0.72	0.63	0.58
ALL SITES	mean	61.85	8.40	7.67
[449 buses]	std dev	67.62	6.06	5.05
	c.v.	1.09	0.72	0.66

TABLE 4 SUMMARY OF EXPRESS BUS DWELL TIME DATA BY METHOD OF FARE COLLECTION FOR THREE TYPICAL FALL BUSINESS DAYS, 4:30 TO 5:30 p.m.

SITE NUMBER AND LOCATION [number of buses surveyed]		DWELL TIME (seconds)	NUMBER of PASSENGERS	DWELL TIME per PASSENGER (seconds)
FAREBOX - COINS ONLY	mean	27.81	5.59	6.13
[115 buses]	std dev	15.79	3.56	4.95
	c.v.	0.57	0.64	0.81
NO FAREBOX	mean	44.04	7.65	7.15
[83 buses]	std dev	36.24	5.88	5.01
	c.v.	0.82	0.77	0.70
FAREBOX - COINS, BILLS	mean	83.33	9.94	8.55
[251 buses]	std dev	80.83	6.50	4.91
	c.v.	0.97	0.65	0.57
COMBINED BILL ACCEPTANCE	mean	73.57	9.37	8.21
[334 buses]	std dev	74.32	6.43	4.97
	c.v.	1.01	0.69	0.61
ALL METHODS	mean	61.85	8.40	7.67
[449 buses]	std dev	67.62	6.06	5.05
	c.v.	1.09	0.72	0.66

distribution of service time per passenger, P. Also, the difference between the mean P for coins only and the mean P for combined bill acceptance is statistically significant at the 95 percent confidence level, confirming earlier findings regarding boarding times when bills are used. Further, the difference between the mean P for coin-and-bill fareboxes and the mean P for payment to the driver is also statistically significant at 95 percent confidence, implying that humans process bills less slowly than do machines.

In light of the recommended boarding times specified in the *HCM* (*1*), even the lowest average value of 5.52 sec per passenger warrants an explanation. The fare for each of the outer-borough express services was \$3.50 at the time of the survey. The three coin-only carriers (New York City Transit Authority, Triboro Coach, and Green Bus Lines) accept silver currency and subway tokens; NYCTA also accepted at the time of the survey a special express token that has since been phased out. The typical patron of these operators' services, then, used at least 5 coins (three subway tokens and two quarters) and often as many as 14 coins (if payment was entirely in quarters). This number of coins is far greater than what would be required for typical multicoin fares, and therefore should lead to longer than average boarding times.

The next step was to regress the dwell time D against the number of passengers N and then introduce BILLS, bus-induced delay B, and traffic delay T into the model. The resulting equations, all of whose coefficients are significant at 95 percent confidence level, are as follows:

$$D = -6.33 + 8.12N \qquad R^2 = 0.53 \qquad (2)$$

$$D = -15.78 + 7.80N + 16.32\,\text{BILLS} \qquad R^2 = 0.54 \qquad (3)$$

$$D = -15.96 + 7.62N + 14.51\,\text{BILLS} + 26.64B \qquad R^2 = 0.56 \qquad (4)$$

$$D = 8.07N^{0.89} \qquad R^2 = 0.67 \qquad (5)$$

$$D = 6.63N^{0.84}\exp(0.40\,\text{BILLS}) \qquad R^2 = 0.70 \qquad (6)$$

$$D = 6.65N^{0.83}\exp(0.39\,\text{BILLS} + 0.20B) \qquad R^2 = 0.71 \qquad (7)$$

The exponential models produced a higher correlation, and did not produce negative dwell times for zero boarding passengers. Note that the inclusion of B in Equation 7 contributed less than 0.01 to the value of R^2. However, the coefficient's t-statistic was 2.59, indicating statistical significance at 95 percent confidence; B was therefore retained.

ANALYSIS OF VOLUMES AND THEORETICAL CAPACITIES

A further analysis of bus volumes and capacities was made for bus stops along each avenue. Such an approach produces a more meaningful way of examining the effects of additional buses at existing stops. The analysis builds on the methods set forth in Chapter 12 of the *HCM* (*1*).

The capacity of a bus stop on an arterial street is given in Equation 12–10(b) of the *HCM* (*1*):

$$c = \frac{3{,}600\ (g/C)R}{t + (g/C)D} \tag{8}$$

where

c = the capacity of the stop (buses per hour);
g = green plus amber time per cycle (sec);
C = cycle length (sec);
R = reductive factor to compensate for dwell time and arrival fluctuations;
t = clearance time between buses (about 15 sec); and
D = average bus dwell time (from Table 1).

Of the variables appearing in Equation 8, both c (the one of interest) and R (an input) are unknown at the outset; c must therefore be computed in a roundabout fashion. Because R, the reductive factor, accounts for variations in arrivals and dwell times, it serves much the same role as the standard deviation s of dwell time. It follows, then, that R can be replaced in the equation by some function of s, as in Equation 9.

$$c = \frac{3{,}600\ (g/C)}{t + (g/C)\ (D + zs)} \tag{9}$$

where z is the value of the standard normal random variable corresponding to the expected or assumed probability that the bus stop will operate efficiently.

Of prime importance here is the concept of efficiency. Under ideal conditions, a bus should be able to enter a stop, perform its service, and leave the stop without waiting for the preceding bus to do the same. When this ideal is violated, failure occurs: queues form and spill over into mixed traffic lanes. If this process tends to happen 30 percent of the time, then the stop is said to operate at 30 percent failure, or 70 percent efficiency. In general, for any efficiency rate E, the unknown is z such that $P(Z < z) = E$. The *HCM* (*1*) suggests 70 percent, giving $z = 0.524$, as a conservative rate of efficiency.

Values of c for each site were computed from Equation 9 and then backsubstituted into Equation 8 to obtain values of R. Table 5 presents these values for 30 and 15 percent failure. (The latter is used for comparison.) The average R value for 30 percent failure is 0.814, which compares well with the value of 0.833 suggested in the *HCM* (*1*).

In Tables 6 and 7 (for 30 and 15 percent failure, respectively), these theoretically derived capacities are adjusted for deviations in the distribution of peak-hour traffic through multiplication by a peak-hour factor of 0.91 (generally accepted for the analysis of New York City traffic).

The number of boarding positions, or berths, at each site was determined from field observation. These were converted into effective berths on the basis of the physical characteristics of each site and the berth efficiency factors given in *HCM* Table 12–19. For example, the four physical berths at each of Sites 1 and 2 became 2.45 effective berths. However, the two berths at each of Sites 4, 6, and 7 are far enough apart to qualify as two effective berths.

The observed flow rates from Table 3 were divided by the adjusted capacities to obtain ratios of bus volume to bus capacity. The disparity between values for sites on the same corridor is explained by the similar disparity in the dwell times for the same sites (see Table 3). For example, the dwell time and bus v/c ratio are much higher for Sites 1 and 3, respectively, than for Sites 2 and 4, respectively.

As can be seen, the locations on Madison and Fifth Avenues operate close to or at capacity. In this respect, the capacity computations verify visual observations of bus operations. Sixth Avenue appears to provide a substantial capacity reserve. However, these capacities may be overstated, because they are not adjusted for blockages on ineffective green time. Thus,

TABLE 5 VALUES OF c AND R ASSUMING FAILURE RATES OF 30 AND 15 PERCENT

SITE		30% FAILURE		15% FAILURE	
		C	R	C	R
#1	Madison Av/44-45 St	17.20	0.73	13.57	0.57
#2	Madison Av/46-47 St	36.62	0.82	31.17	0.70
#3	Fifth Av/48 St	25.96	0.81	21.91	0.68
#4	Fifth Av/43-42 St	39.41	0.79	32.76	0.66
#5	Fifth Av/41-40 St	57.95	0.87	51.29	0.77
#6	Sixth Av/43-44 St	54.15	0.88	48.67	0.79
#7	Sixth Av/44-45 St	37.56	0.80	31.43	0.67

TABLE 6 THEORETICAL CURB LANE CAPACITIES AND *v/c* RATIOS AT 30 PERCENT FAILURE BETWEEN 4:30 AND 5:30 p.m.

SITE*	R	THEORETICAL CAPACITY (buses/hr)	NUMBER of ACTUAL BERTHS	NUMBER of EFFECTIVE BERTHS	PEAK HOUR FACTOR	ADJUSTED THEORETICAL CAPACITY		OBSERVED FLOW RATE along BLOCKFACE	VOLUME/ CAPACITY RATIO
						per BERTH (buses/hr)	BLOCKFACE (buses/hr)		
#1 Madison Av/44-45 St	0.73	17.20	4	2.45	0.91	15.65	38.35	34	0.89
#2 Madison Av/46-47 St	0.82	36.62	4	2.45	0.91	33.32	81.64	45	0.55
#3 Fifth Av/48 St	0.81	25.96	2	1.75	0.91	23.63	41.35	36	0.87
#4 Fifth Av/43-42 St	0.79	39.41	2	2.00	0.91	35.86	71.73	48	0.67
#6 Sixth Av/43-44 St	0.88	54.15	2	2.00	0.91	49.28	98.56	18	0.18
#7 Sixth Av/44-45 St	0.80	37.56	2	2.00	0.91	33.66	67.32	14	0.21

* Volumes recorded at site #5 are unreliable due to construction at 41st Street.

TABLE 7 THEORETICAL CURB LANE CAPACITIES AND *v/c* RATIOS AT 15 PERCENT FAILURE BETWEEN 4:30 AND 5:30 p.m.

SITE*	R	THEORETICAL CAPACITY (buses/hr)	NUMBER of ACTUAL BERTHS	NUMBER of EFFECTIVE BERTHS	PEAK HOUR FACTOR	ADJUSTED THEORETICAL CAPACITY		OBSERVED FLOW RATE along BLOCKFACE	VOLUME/ CAPACITY RATIO
						per BERTH (buses/hr)	BLOCKFACE (buses/hr)		
#1 Madison/44-45	0.57	13.57	4	2.45	0.91	12.35	30.25	34	1.12
#2 Madison/46-47	0.70	31.17	4	2.45	0.91	28.36	69.48	45	0.65
#3 Fifth/48	0.68	21.91	2	1.75	0.91	19.94	34.89	36	1.03
#4 Fifth/43-42	0.66	32.76	2	2.00	0.91	29.81	59.62	48	0.81
#6 Sixth/43-44	0.79	48.67	2	2.00	0.91	44.29	88.57	18	0.20
#7 Sixth/44-45	0.67	31.43	2	2.00	0.91	28.60	57.20	14	0.24

* Volumes recorded at site #5 are unreliable due to construction at 41st Street.

the actual road space available for new buses is less than that presented in the tables.

IMPLICATIONS

The following implications are apparent from the preceding analyses:

1. The overly long passenger service times (up to 9.22 sec per passenger) reflect the use of dollar bills and large numbers of coins. These service times could be reduced if passengers were permitted and encouraged to use a single token, a pass, or any other time-saving mechanism.
2. The reductive factor value of 0.833 set forth in the *HCM* (*1*) for 30 percent failure appears reasonable. The study yielded values between 0.73 and 0.87, with an average of 0.814.

3. The *HCM* (*1*) methodology for estimating the capacity of a bus stop provides reasonable results—but only when buses have full use of the curb lane. When the lane is shared with other traffic, appropriate deductions must be made.

On streets such as Fifth and Madison Avenues, buses have use of designated berths and dedicated lanes. This policy gives much higher capacities than those obtained from the *HCM* (*1*) equation for a single bus stop. More research should be undertaken into both the interactions of buses with mixed traffic in such lanes and the efficiency of multiberth bus stops. These are promising areas for further investigation.

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Planning and Implementing Bus Route Changes To Serve New Rapid Transit Lines: The Archer Avenue Experience in New York

DANIEL K. BOYLE

On December 11, 1988, the New York City Transit Authority opened the Archer Avenue Rapid Transit Line in Jamaica, Queens. Along with this subway extension, bus routes from Southeastern Queens were rerouted to serve the new rapid transit line. The planning process and ultimate bus service plan for Archer Avenue are described. Elements of the marketing effort are presented, and the actual operation of the bus routes in the first 6 months following the change is analyzed. The conclusions address factors that either contributed to, or detracted from, the overall success of this project. Negative factors included legal issues with the Jamaica Chamber of Commerce and delays in construction of the bus canopy at Archer Avenue. Factors contributing to the success of the project were innovations in providing limited-stop bus service in the Merrick Boulevard corridor, establishment of convenient intermodal transfer facilities, and aggressive marketing of service changes.

Over the past 15 years several cities have constructed new rail rapid transit lines, which involved the restructuring of bus systems. Previously the major transit link to downtown, buses within the rail rapid transit corridor will assume the function of feeder service to the rapid transit line. The potential market for rail rapid transit service can be maximized while vehicle congestion on downtown streets is reduced and passengers are provided with a faster ride.

In the 1970s, the Jamaica Avenue elevated structure was torn down in downtown Jamaica. On December 11, 1988, the New York City Transit Authority (NYCTA) opened the Archer Avenue Rapid Transit Line in Jamaica, Queens. This new two-level, three-station, four-track subway extension restored J line service between Jamaica and lower Manhattan. It also shifted E line express service to midtown and lower Manhattan from Hillside Avenue to Archer Avenue (Figure 1). Originally, the extension was to continue into southeastern Queens, an area without rapid transit service, but the fiscal crisis in the previous decade forced a cutback in the scope of the project. The terminus of the Archer Avenue line was only ½ mi from the existing Hillside Avenue line and did not have a great deal of residential density nearby. An essential to the success of the project was feeder bus service. However, the restructuring of bus service did not involve the conversion of radial routes to feeder routes, but rather, the shift of feeder routes from one rapid transit line on Hillside Avenue to a new location on Archer Avenue. These two avenues form the northern and southern boundaries of the Jamaica central business district (CBD), which is one of the two major commercial areas in Queens.

The change in bus service created by the opening of the Archer Avenue line is described. The planning process, ultimate bus service plan, and constraints are noted. Elements of the marketing effort are presented. Actual operation of the bus routes in the first 6 months after the change is also discussed. The conclusions focus on important points contributing to, or detracting from, the overall success of the bus system revisions.

BUS SERVICE AREA

The NYCTA bus service from Jamaica is oriented toward the east and southeast, which is the origin for trips into Jamaica. There are two main corridors by which buses enter and leave the Jamaica CBD—Hillside Avenue from the east, and Merrick Boulevard from the south (Figure 1). Before the opening of the Archer Avenue line, passengers in the Hillside Avenue corridor gained access to the E and F Queens Boulevard express trains at 179th Street, which was the first stop on both lines. Passengers in the Merrick Boulevard corridor entered at the 169th Street station, where only the E train stopped during peak hours. On leaving Jamaica, the bus routes serve the various communities of eastern and southeastern Queens. The six Merrick Boulevard corridor routes are of primary interest in terms of service planning for Archer Avenue.

Local bus service is also provided by four private bus companies in Queens, three of which also serve Jamaica. Only Jamaica Bus Corporation, which enters Jamaica from the south via Guy R. Brewer Boulevard and 160th Street, made any changes to their route structure as a result of the opening of the Archer Avenue line. The changes were relatively minor. The Metropolitan Suburban Bus Authority (MSBA), a public authority and Metropolitan Transit Authority (MTA) subsidiary that operates buses in Nassau County, has several routes connecting with the subway in Jamaica. Most of these routes enter Jamaica via Hillside Avenue. Only one enters Jamaica via Merrick Boulevard.

The NYCTA and private bus companies operate a few bus routes that enter Jamaica from the north. However, travel volume into Jamaica from northern areas is relatively low

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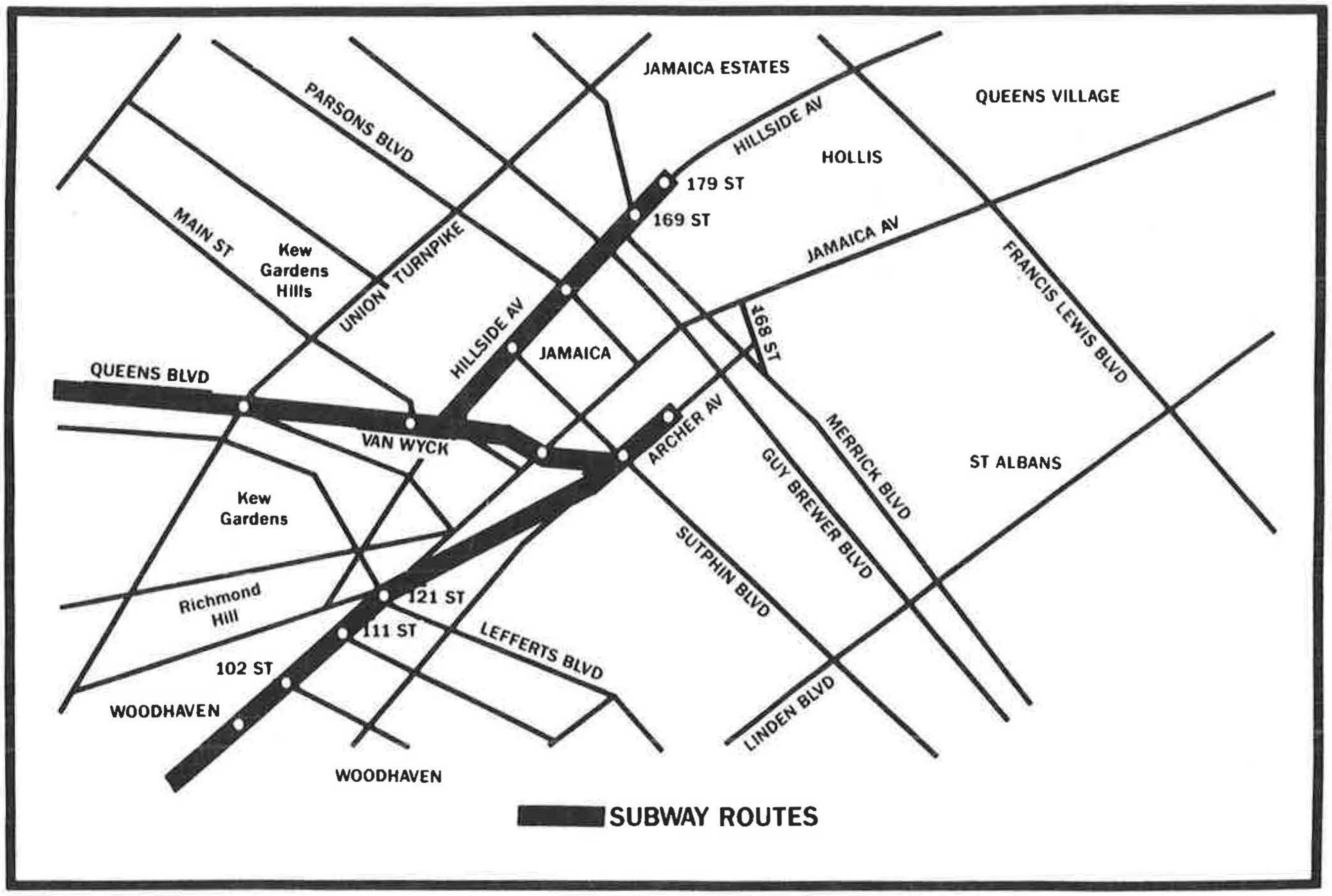

FIGURE 1 Archer Avenue and Hillside Avenue subway routes.

because there are more convenient ways to travel either to the Queens Boulevard subway or directly into Manhattan using private express bus routes. Competing commercial areas are also within easy reach.

PLANNING PROCESS FOR ARCHER AVENUE BUS SERVICE

Once an opening date was established, the NYCTA accelerated the process of planning bus service to the new Archer Avenue line. The operations planning department of the Authority was tasked with planning service for both the rapid and surface transit. The operations planning department was also responsible for the coordination of bus and rail planning. At the outset of this process, attention was focused on the Merrick Boulevard corridor routes. These routes were located closest to the first station on the Archer Avenue line, and could easily be rerouted without increasing mileage. In addition, experience elsewhere in New York City indicated that the majority of riders transfer from bus to rapid transit at the first available opportunity. However, even if Hillside Avenue routes were extended to Archer Avenue, it was considered unlikely that any significant number of riders would opt for a longer bus ride to reach the new station. Southeastern Queens, which the Archer Avenue line in its original form was intended to serve directly, seemed the most logical source of ridership for the new line. A preliminary decision was made to focus on the Merrick Boulevard corridor buses as candidates to be rerouted to Archer Avenue.

Before completing this choice, an origin-destination survey of Merrick Boulevard corridor bus passengers was undertaken. Riders were counted and received a survey card as they departed one of the six Merrick Boulevard corridor routes in Jamaica between the hours of 5:30 a.m. and 3:30 p.m. on Monday, June 1, 1987. Jamaica-bound riders boarding Merrick Boulevard corridor buses during these hours were also counted and surveyed. Survey cards were distributed to 54 percent of the 21,500 passengers, and 1,020 usable surveys were returned, representing 8.8 percent of the total number of surveys distributed.

Survey results showed that 68 percent of Merrick Boulevard corridor bus passengers boarded the subway in Jamaica, whereas 23 percent transferred to another bus and 9 percent walked to their final destination (*1*). The percentage of bus passengers bound for the subway was fairly constant at all times of the survey and slightly higher in the midday period than in the peak period. This emphasized the importance of quick, direct access to the subway throughout the day for Merrick Boulevard corridor bus riders. However, in providing subway access it was also vital to maintain transfer connections for the 23 percent of passengers who took another bus once they arrived in Jamaica. Any service plan needed to take into consideration the convenience of these riders because Jamaica was the final destination of only 9 percent of the Merrick Boulevard corridor bus riders.

The parameters of the service plan emerged from the results of the origin-destination survey. Direct access to the subway, maintenance of the connectivity of the existing bus route system, and continued access to the Jamaica CBD were primary goals. Three proposals incorporating various options to meet these goals were drawn up and presented at a public hearing in February 1988. The proposals differed primarily in how bus connections in the Hillside Avenue corridor were maintained. One proposal called for the continuation of one Merrick Boulevard corridor route along its current path to Hillside Avenue, a second for the extension of selected routes from Hillside Avenue to Archer Avenue, and a third for a new route connecting the two corridors and traversing the Jamaica CBD.

Because of the magnitude of the Archer Avenue project, the public hearing process was modified to permit greater community input. Usually, a specific proposal is presented at a single public hearing and is then forwarded, along with oral and written public comments, to the MTA Board for a vote. In this case, the first public hearing presented options under consideration. After public comment was received, a proposed service plan was presented at a second public hearing in June 1988. The service plan was presented in two phases to ensure maximum opportunity for community participation. This proposal was then further modified and finalized in August 1988.

In addition to the public hearings, an extensive community outreach effort was carried out throughout 1988. Members of the NYCTA government relations unit met informally with local politicians, community board members, and community groups to explain the rationale for the proposed changes.

The planning process also addressed the operational needs of the project, including passenger drop-off and boarding areas, and a staging area for buses. An entire block along Archer Avenue, adjacent to the main station entrance, was designated as the drop-off area. On the opposite side of the street, where passengers would exit the subway and board the buses, a canopy was designed to extend the length of the sidewalk between the two station exits. Exclusive bus lanes alongside the canopy were planned to allow buses to enter and leave the boarding area quickly. Beyond the station, a narrow roadway, separated from Archer Avenue by an island, was widened to be used as a staging area for buses. This area is called a teardrop and allows most buses to avoid a loop around the block in turning around. Finally, to maximize subway-bus coordination during peak hours, a holding light was planned for the canopy to enable buses to meet arriving trains.

THE ARCHER AVENUE BUS SERVICE PLAN

The Archer Avenue bus service plan was prepared at the conclusion of the public hearing process. The plan called for the rerouting of the six Merrick Boulevard corridor bus routes to serve the Archer Avenue line (Figure 2). Three routes operating along or across Hillside Avenue were extended to Archer Avenue (Figures 3 and 4), and walking transfers were provided to other Hillside Avenue routes. The decision of what routes to extend was guided by the results of the origin-destination survey, which indicated the routes Merrick Boulevard corridor riders transferred to most frequently. Two of the extended routes were continued past the first stop of the new Archer Avenue line to connect with the Long Island Rail Road Jamaica station. The walking transfers to other Hillside Avenue routes involved a two-block walk from Archer Avenue to the 165th Street bus terminal, where most of the Hillside Avenue corridor bus routes originate. The combination of rerouting, route extensions, and walking transfer privileges met the goals of subway access and connectivity. An analysis of the destinations of Merrick Boulevard corridor bus passengers that did not transfer to the subway or another bus revealed that the majority would not be adversely affected by the rerouting.

The service plan was not without opposition. Community members and local politicians called for a choice of destinations between Archer and Hillside Avenues for Merrick Boulevard corridor passengers, either by rerouting some routes in the corridor or by establishing multiple destinations for each route. Some also called for Hillside Avenue corridor bus routes to serve the new Archer Avenue line. The Jamaica Chamber of Commerce argued that the plan would take potential customers farther away from their stores. Speakers at the public hearings also expressed views that rerouting certain routes did not take advantage of the opportunity to make more dramatic improvements in service.

In its final bus service plan (*2*), the NYCTA responded to some of the community proposals but disagreed with others. Public demand for a choice of destinations in Jamaica appeared reasonable; however, the Authority was opposed to split destinations for any route. Confusion and inefficient operation would result in rerouting some Merrick Boulevard corridor routes to Archer Avenue while leaving others at Hillside Avenue. The Authority also considered this demand to be prompted by existing conditions. Archer Avenue was perceived as desolate and forbidding whereas Hillside Avenue was more familiar. In addition, the Hillside Avenue and 169th Street station had express service at the time, but would have only local service under the rapid transit portion of the Archer Avenue service plan. There were no intermodal facilities at Hillside Avenue, not even shelter from inclement weather, and the subway station itself had narrow platforms. At Archer Avenue, on the other hand, an extensive bus canopy was planned, and station amenities were superior. The final bus service plan rerouted all Merrick Boulevard corridor bus service to Archer Avenue to conform with the goals of providing direct access to the new subway station and expediting subway service.

The Jamaica Chamber of Commerce argued to route the subway via Jamaica Avenue in off-peak hours. Jamaica Avenue is the spine of the CBD and one block north of Archer Avenue. However, congestion along Jamaica Avenue, additional distance and travel time required, and the 70 percent of Merrick Boulevard corridor bus passengers bound for the subway in the midday period led the NYCTA to change the more direct route via Archer Avenue at all times of the day. One bus route entering Jamaica from the west via Jamaica Avenue was extended to the eastern end of the CBD and increased the number of bus routes to four along Jamaica Avenue in the CBD. To meet the concern that the NYCTA was abandoning the northern half of the CBD, a Hillside Avenue corridor bus route that had previously terminated at

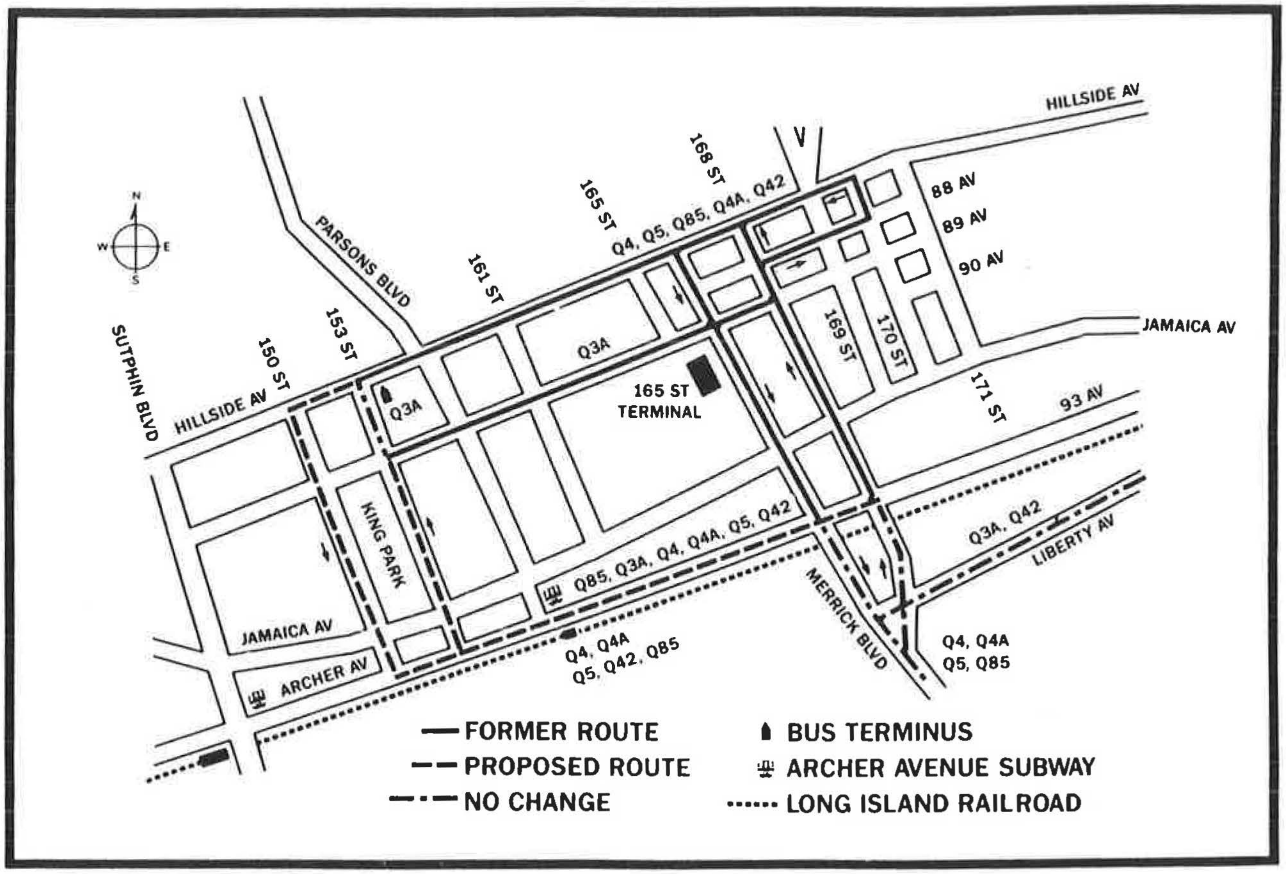

FIGURE 2 Merrick Boulevard corridor rerouting.

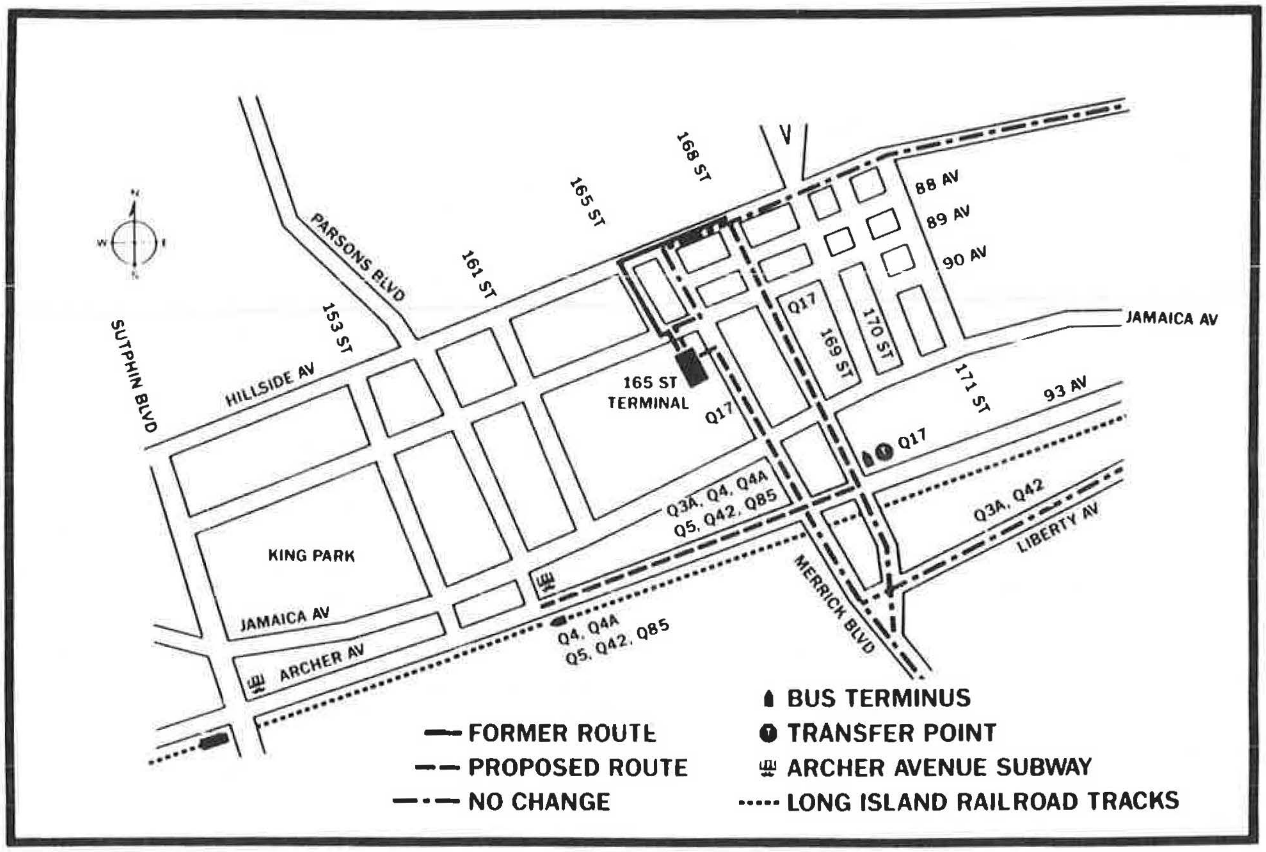

FIGURE 3 Q17 extension.

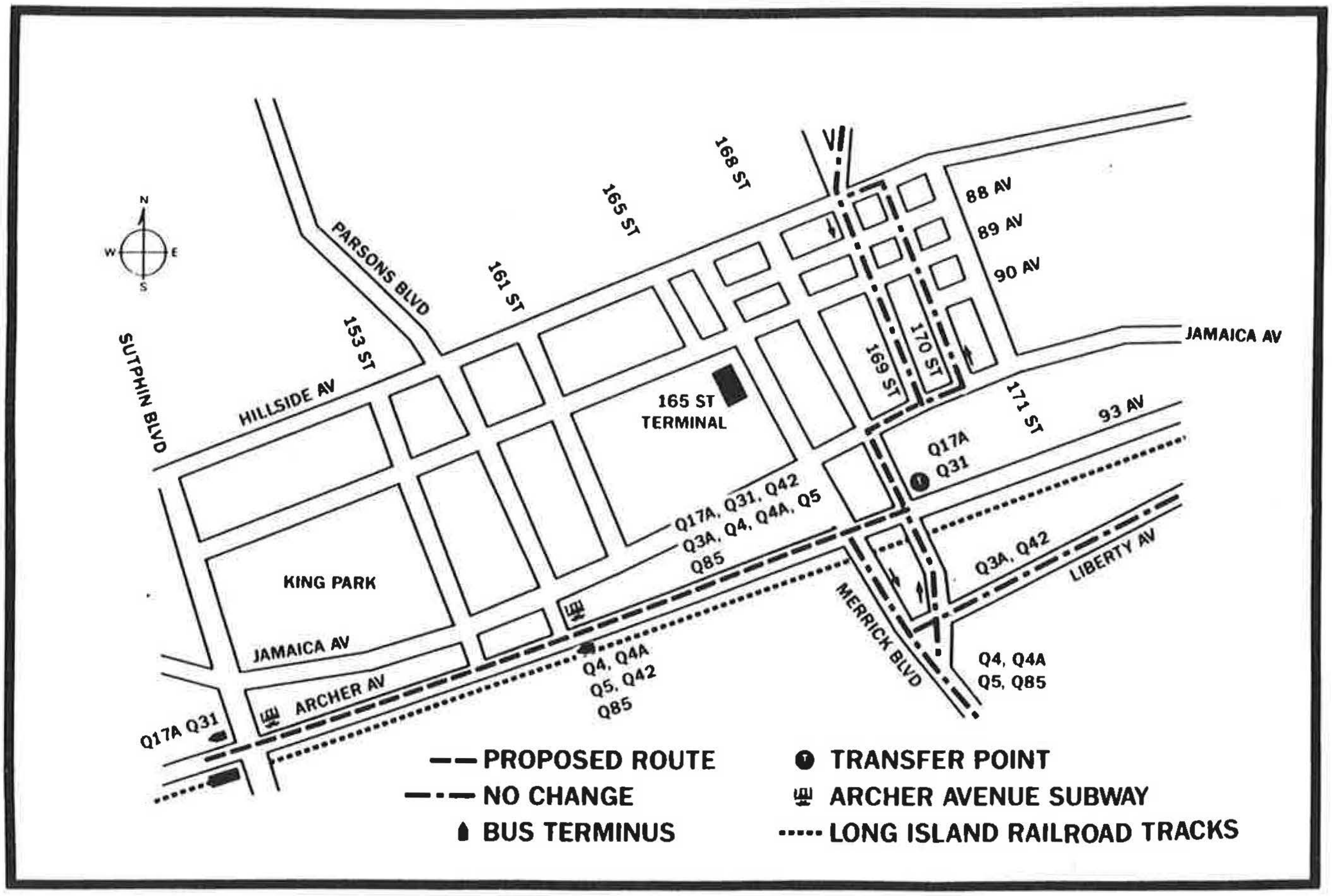

FIGURE 4 Q17A/Q31 route extension.

the first subway stop at 179th Street was extended to the 165th Street terminal. Plans also were advanced to upgrade the terminal, which was an old facility in a state of general disrepair.

A major feature added to the bus service plan after the public hearings was limited-stop service on three of the six routes serving the Archer Avenue line. On each route, limited-stop buses in the peak hours continue to make all stops on the outer portion of the route but stop only at major transfer points on the route's inner portion. Short-turn buses make all local stops on the inner portion of the route. Limited-stop service reduces travel time by 5 min and continues to provide all transfer connections on the route.

Another advantage to limited-stop service was that the decrease in travel time would allow the NYCTA to compete more effectively with the vans that have dominated in Southeast Queens over the past decade. Some of the vans are regulated by New York State; however, the majority operate illegally, are unregistered and uninsured, and do not adhere to traffic regulations. Limited-stop service would allow the buses to compete with the vans in terms of travel time and regain some of the ridership lost in recent years.

The bus service plan submitted for approval to the MTA Board contained the following major elements:

- Direct bus service to the Archer Avenue line by rerouting the six Merrick Boulevard corridor buses;
- Connections provided by the extension of selected Hillside Avenue routes and by provision of walking transfers between Archer Avenue and the 165th Street bus terminal; and
- Limited-stop service in peak periods on three of the six Merrick Boulevard corridor routes.

The MTA Board voted to approve this service plan. However, the Jamaica Chamber of Commerce brought a lawsuit to prevent the plan from going into effect. The bus changes did take place in conjunction with the opening of the Archer Avenue line on December 11, 1988. However, the out-of-court settlement between the Transit Authority and the Jamaica Chamber of Commerce introduced a new circulator route within the Jamaica CBD, extended two more Hillside Avenue corridor routes to the 165th Street bus terminal, and proposed an extension of certain bus routes operated by a private carrier to the 165th Street terminal from an on-street layover two blocks away.

MARKETING

The marketing effort for the Archer Avenue line had both city-wide and local aspects. Rapid transit changes affecting Brooklyn and Manhattan were also scheduled to take place on December 11. The first new segment of a rapid transit line in 20 years, the central focus of the advertising campaign was the opening of Archer Avenue. A local advertising agency was engaged to prepare the advertising campaign.

The city-wide campaign included full-color brochures, newspaper and radio advertisements, a Sunday newspaper insert, and new subway maps. The bus route changes were mentioned in several of these efforts but the local aspect of the marketing effort focused on mailings to thousands of Southeastern Queens households and on preparation of specific route brochures. Eleven new bus brochures for the six Merrick Boulevard corridor routes and the routes being extended were prepared by the Transit Authority's marketing department. Each brochure included a route map, transfer locations, a description of the changes in the route, and a timetable. The brochures for the three routes receiving limited-stop service also included a description of the new service. The effort was the first large-scale preparation of route-specific brochures and timetables, although brochures had been distributed for individual bus routes on the occasion of route changes.

A large part of the challenge of any marketing campaign is ensuring that the material reaches its intended audience. A direct mailing to households with zip codes served by the Merrick Boulevard corridor bus routes reached people who did not use public transportation and those who did not read newspapers. Although no formal study of its effectiveness has been undertaken, this technique had been used in previous cases of route extensions and had elicited positive feedback from the community.

Distribution of the route-specific brochures on the buses was more chaotic. One of the hallmarks of the Archer Avenue project was that different departments within the NYCTA worked closely together to ensure its success. However, this approach did not lend itself to the establishment of procedures to be carried over after the changes were in effect. Consequently, the depots' supply of brochures for certain routes was reduced quickly. After the first few days, the majority of buses either had no brochures or brochures for a different route. At bus stops, information was available in the form of maps and timetables contained in guide-a-ride cannisters (attached to poles at bus stops) and was updated for all affected routes before December 11. Efforts have since been undertaken to make the reprinting and restocking of route brochures a routine process.

The marketing effort overall was successful in achieving its primary goal to inform riders of the December 11 changes. Specific route improvements such as limited-stop peak-period bus service may have received more attention in a less hectic atmosphere, in which there were not so many systemwide changes. The marketing effort needed to focus more on information and less on enticements to use the system because of the magnitude and sheer volume of service changes taking place on December 11. Follow-up work has been limited, mostly involving second printings of the bus route brochures.

OPERATION

Prior to the Archer Avenue opening, plans were designed to monitor various aspects of bus operations. Among the elements to be monitored were the overall operation at the Archer Avenue station, particularly in the evening peak period, limited-stop service, operation of the extended routes, and transfer activity. Traffic checkers were deployed extensively to measure ridership.

Because the rerouted Merrick Boulevard corridor buses stopped within sight of the subway entrance, the morning peak period did not present a problem at the station. Several Transit Authority personnel were stationed at the major transfer point to reach Hillside Avenue, to assist riders in finding their bus. Morning operations on December 12, 1988, proceeded smoothly. However, there was more transfer activity than expected. In the evening peak period, employees were posted at the subway exits to steer riders to their buses. Because construction of the bus canopy at Archer Avenue was delayed, a temporary canopy was built with a narrow wooden sidewalk and signs at the bus stops for each of seven routes—the six Merrick Boulevard corridor NYCTA routes and one route operated by the Metropolitan Suburban Bus Authority. Buses were staged in a turnaround area to the west of the canopy. For the first two evenings, employees at the canopy would contact a dispatcher in the staging area when a bus was needed for a particular route. Intended to match bus departures with the arrival of subway passengers, this procedure resulted in long lines, service delays, crowded conditions under the temporary canopy, problems at the major transfer point several blocks to the east, and considerable passenger disgruntlement. Late in the second evening peak period, the decision was made to dispatch buses from the staging area only according to the route schedules. By the evening of the third day, the combination of schedule-based dispatching of buses and increased passenger familiarity, both with the layout of the canopy and the new station, considerably eased the operating problems and allowed the intermodal transfer point to operate as planned. The concentration of passengers and buses for seven routes in a clearly demarcated area has to a large extent kept unlicensed, illegal vans from operating at the canopy and siphoning off NYCTA passengers. Traffic enforcement in the first two weeks by the New York City Department of Transportation also helped to keep traffic moving and to keep illegal vans out of the canopy area.

Transfer volumes exceeded expectations at the Merrick Boulevard corridor major transfer point, Archer Avenue and 165th Street, which was redesigned on the first day of operation. A universal stop at the transfer point approximately one-half block in length was extended to cover nearly two blocks, and dedicated stops for each route were established. This change, along with the presence of NYCTA employees to direct transferring passengers to the appropriate bus stop, enabled the transfer point to function effectively. However, there is still inadequate shelter for waiting passengers on the narrow sidewalks and unresolved disputes with property owners. The peak demand for passengers transferring to Merrick Boulevard corridor buses occurred at 3:00 p.m., which indicated a high proportion of transferees were intermediate and high school students. It was hypothesized that a low proportion of these students had responded to the origin-destination survey, leading to low predicted transfer volumes, with actual transfer volumes heavier than expected. Also, lack of knowledge of the rerouting or a resistance to changing established travel patterns may have inflated transfer volumes in the first weeks of operation.

Limited-stop bus service presented no problem in the morning because the overwhelming majority of passengers were either bound for Jamaica or alighted at a transfer point. However, in the evening, passengers had to learn to look not just for their route but also for either a local or a limited bus. There was insufficient room at the temporary canopy to form two separate lines for buses, and considerable confusion was created. However, if a more pronounced education effort had been undertaken before the Archer Avenue opening and focused on the actual operation of limited-stop service, much of this confusion would have been prevented. As riders became accustomed to limited-stop service, it met with a high degree of acceptance and approval. Observations indicated a balance in local and limited peak-period loads. Passengers on one of the Merrick Boulevard corridor routes not served by limited-stop buses petitioned to extend limited-stop service to their route. The general acceptance to limited-stop service has led the Transit Authority to explore its use in the Hillside Avenue corridor.

The two bus routes crossing Hillside Avenue that were extended to the Jamaica Long Island Rail Road station proved to be more heavily used than anticipated, especially in the morning peak hours. The original proposal had been questioned by some who doubted that there was any demand for access to or from the train station. The extension to the train station resulted in an average of 20 additional passengers on each bus in the morning peak hours during the first weeks of operation even though it is not the heaviest route segment.

In an out-of-court settlement reached between the NYCTA and the Jamaica Chamber of Commerce, a new downtown circulator route was established. Transfer privileges were revised to make it easier to transfer between buses in the Hillside Avenue and Merrick Boulevard corridor. The Jamaica link operates on a 15-min headway for most of the day and has been poorly patronized. Were it not for the special circumstances surrounding the birth of this route, it would be high on the list of routes to be discontinued. Its low ridership translates to a low use of the new transfer privileges, which to date have not been subject to abuse.

The latest combined ridership figures on the Archer Avenue and Merrick Boulevard corridor routes reveal ridership increases overall on five of the six individual routes. On the Q83, the only route showing a decline in riders, a morning branch to the 179th Street and Hillside Avenue subway station was discontinued. Some of these riders are now served by a different route. Table 1 presents these ridership figures. However, revenue on Jamaica Depot bus routes—five of the six Merrick Boulevard corridor routes operate out of the Jamaica Depot—decreased by 4 percent between February 1988 and February 1989. These conflicting reports indicate that it will take time to determine the ultimate impacts on ridership and revenue, of the rerouting of Merrick Boulevard corridor buses. Recent counts on the Q4 indicate that limited-stop service is functioning as planned, with slightly heavier loads on limited trips. The most recent ridership count on the new Jamaica link downtown circulator shows only 170 daily riders on 53 trips.

TABLE 1 BEFORE-AND-AFTER RIDERSHIP ALIGHTING MERRICK BOULEVARD CORRIDOR BUSES IN THE MORNING PEAK PERIOD AT THE SUBWAY IN JAMAICA

	Number of Riders		
Route	Prior to Archer Avenue[a]	After Archer Avenue[b]	Percent Change
Q4	2,120	2,472	+14
Q5	1,556	2,124	+27
Q42	383	554	+31
Q83	2,345	2,081	−13
Q84	1,214	1,473	+18
Q85	2,360	2,821	+16
Total	9,978	11,525	+13

[a] Prior counts: October 1986, August and October 1987, March and June 1988.

[b] After counts: January, February, and March 1989.

CONCLUSION

The Archer Avenue experience suggests four major factors vital in determining the success of a service change of this magnitude: (a) real benefits for riders, (b) communication of the nature of the service changes and benefits to both riders and potential riders, (c) coordination with the business community and local political groups, and (d) a willingness to innovate. The following paragraphs summarize the effects of these factors in the implementation of the Archer Avenue bus service changes.

The rerouting of heavily traveled buses to serve a new rapid transit line is often seen as a simple restructuring of service to make more efficient use of facilities and resources. However, from the riders' perspective it is a forced change in established travel routines. Conveying accurate and timely information concerning both the change itself and the reasons for the change is of prime importance in making a successful transition to the new route structure. It helps to offer increased amenities and a faster trip as a result of the change. Among the primary benefits of rerouting bus service to Archer Avenue were a much improved chance of getting a seat on the subway (because this was the beginning of the line), a choice of subway service, and an improved environment for transferring between subway and bus.

The marketing and community outreach efforts emphasized these benefits and provided not only news on the changes taking place but also information not previously available such as bus timetables. The direct mailing might have been enhanced by a brief brochure outlining upcoming service changes, transfer locations, and answers to frequently posed questions, and distributed directly to Merrick Boulevard corridor bus passengers 1 or 2 weeks before the implementation date. Although this additional step appears redundant, experience in the first week after the rerouting indicated that, despite direct mailings, newspaper advertisements, and public notices, many riders were still unaware of what was happening. Local politicians, community board members, and members of the business community were kept fully abreast of all of the changes. It is possible that because the marketing effort addressed city-wide changes, some Merrick Boulevard corridor riders did not bother to check fully how these changes might affect them. Among the implications for future marketing efforts is the primary importance of emphasizing specific information on the impacts of service changes. Direct mailings and route-specific brochures, although not universally successful, worked best in providing information on the Archer Avenue changes, whereas newspaper ads and public notices were less successful from this perspective.

The delay in construction of the bus canopy at Archer Avenue and the problems with placing bus shelters at the major transfer point diluted the argument that service to Archer Avenue offered more passenger amenities. Instead of a spacious, well-lit, sheltered waiting area with two lanes of traffic reserved for buses, bus passengers at Archer Avenue were crowded under a temporary canopy and buses pulling away from the curb were forced to negotiate regular traffic. Another city agency was responsible for construction of the canopy, but the excessive delays focus attention on the importance of ensuring that all amenities are in place at, or soon after, the service change. Although the temporary canopy provided overhead shelter that Merrick Boulevard corridor passengers did not have at Hillside Avenue, its narrow sidewalk and unattractive appearance detracted from the perceived benefits.

The positive impact of transit service on local business activity is generally accepted. To outsiders, the intense opposition of the Jamaica Chamber of Commerce to the service plans may seem bizarre. In fairness, the Chamber did not object to the rerouting of peak-period bus service via the most direct route, and certainly did not object to a new rapid transit line. Its concerns focused on the eastern end of the CBD, which it viewed as receiving less direct bus service because passengers bound for businesses in the vicinity of the 165th Street bus terminal or along Jamaica Avenue would now have to walk one to two additional blocks. Its concerns were exacerbated by the closing of the only major department store left in Jamaica in the latter part of 1988. In its out-of-court settlement, the NYCTA added service to the CBD in response to these concerns. However, the origin-destination study of Merrick Boulevard corridor passenger destinations within Jamaica showed that approximately two-thirds of these passengers would have the same or shorter walk under the original service plan. It is possible, but unlikely, that adding this service to the final service plan would have avoided a lawsuit. The most likely outcome would have been continued pressure to compromise further, particularly on using Jamaica Avenue instead of Archer Avenue for off-peak service. The NYCTA has stated that the overall impact of these service changes on the Jamaica business community would be positive. Recent renewed commercial activity in long-dormant storefronts in the vicinity of the new subway station supports this. The new federal office building at the subway station location will also have a positive impact on the health of the Jamaica business community.

The lawsuit and the demands for split service between Archer and Hillside Avenues highlight the inability of transit service to satisfy every travel desire. However, the decision to reroute the Merrick Boulevard corridor buses to Archer Avenue has been borne out by the private sector. The van operators emphasized, at the time of the service changes, that they would continue to serve Hillside Avenue and 168th Street and thus positioned themselves as a clear alternative to NYCTA buses. In the ensuing months, the licensed van organization has petitioned the New York State Department of Transportation to allow their vans to serve Archer Avenue, and many of the unlicensed vans have joined together in a new formal organization that has also filed for permission to serve Archer Avenue.

Finally, a major project of this nature encourages and may force innovations in several areas. Among the key innovations is the provision of limited-stop service on a large scale in the Merrick Boulevard corridor, an idea proposed at the initial public hearing. This service has allowed the NYCTA to compete more effectively with the unlicensed vans in terms of speed, which is the major advantage of vans over buses. The delayed construction of an intermodal transfer facility is a major change from the on-street jumble of bus stops typical of other major transfer points in Queens on Hillside Avenue and in Flushing. The major marketing effort emphasizes a recent trend within the NYCTA of actively marketing its services. The cooperation of various departments within the NYCTA was not only necessary to the success of Archer Avenue but also laid the foundation for working together on other major projects and routine day-to-day issues.

The major changes involved in the Archer Avenue project reflect a determination to examine existing bus service closely and to recommend and implement changes called for by evolving travel patterns and trip destinations. This process, carried on throughout the city on a smaller scale, is perhaps the most important break from the past and resulted in improved and more efficient provision of service reflecting present travel needs.

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Public Transportation Problems and Solutions in the Historical Center of Quito

JACOB GREENSTEIN, LOUIS BERGER, AND AMIRAM STRULOV

Quito, the capital of Ecuador, has recently experienced a 12-percent growth in its activities, and the demand for bus transportation has increased correspondingly. In 1985–1986, this city was served by 81 bus lines. Large buses accounted for 79 percent of the fleet, and small buses accounted for 21 percent. The bus system in Quito was owned and operated by 36 different organizations, companies, and individuals. About 900 buses per hour entered the historical center of Quito. About 95 percent of the buses traveled on routes that circulated through the historical center, even though it was the destination of only about 35 percent of the bus users. In addition, bus schedules did not match the actual fluctuation in user demand, resulting in increased operating costs and time delays. Bus stops were not always in convenient or safe places, and the bus drivers did not always load and unload passengers at assigned bus stops. The bus fleet was old, the buses were usually overloaded, and travel in such conditions was uncomfortable. Finally, the planning and monitoring of route assignments were not carried out properly. The operations of the 36 bus groups were poorly coordinated, and scheduling was not sufficiently sensitive to changes in the demand for bus transportation. Among the solutions adopted were the following improvements: (a) planning, organizing, and managing the public transportation system; (b) regulating traffic and parking; and (c) improving the signalization and local intersections. Only simple and economic solutions were considered.

Over the last 15 to 20 years, the city of Quito, the capital of Ecuador, has grown rapidly because of migration from rural areas and natural growth. For example, the population has increased from 900,000 in 1985 to 1,200,000 in 1989. The demand for such basic urban services as transportation, water supply, sewers, education, and commerce has increased correspondingly and is still growing rapidly. Of special concern are the transportation needs in the historical center of Quito, where the quality of service has rapidly deteriorated. Because funds are limited in the current economic climate in South America, local authorities are looking for simple, practical, and economical solutions to improve the quality of public transportation. A case study has been carried out in the historical area. Although this area covers only 1 km^2, it is key to improving the quality of transportation for a larger part of the city. The study indicated that the main reason for poor service was the high traffic congestion and inefficient management and coordination of the local bus system.

In order to improve public transportation, the following improvements were analyzed: (a) planning and rescheduling the bus routes, (b) improving the administration and coordination of the different bus companies, (c) planning and relocating the bus stops, (d) enforcing new parking regulations, (e) eliminating such traffic hazards as the local street market, (f) scheduling more efficiently the loading and unloading of goods and merchandise, and (g) making simple improvements to the signalization and local intersections. Such improvements are economical and easy to implement and could significantly increase the reliability of the bus services and reduce the users' costs.

Costly improvements, such as major infrastructure rehabilitation or the introduction of mass transportation systems, were not practical. These high-cost improvements take a long time to implement, and the fast growing demand for urban services might cause them to be obsolete before they were operational. A simple methodology was developed and applied to solving the urban public transport problems in the historical center of Quito.

EXISTING PUBLIC TRANSPORT SYSTEM

Quito is between two parallel mountain chains. Because of this special topography, the city developed mainly to the south and north. The historical area, where the city hall, the National Presidential Oval, the court system, and other public buildings are located, is in the middle of the city. Quito's cultural, commercial, and administrative services are concentrated in this center. These services attract heavy public and private traffic into the center, most of which enters and exits through two major streets (Guayaquil and Maldonado), creating the principal corridor shown in Figure 1. Figure 1 indicates the principal road network and the upper limit of the hourly intensity of buses, as determined in 1982. For example, in that year 204 buses traveled along Maldonado Street each hour in each direction. Along Guayaquil Street, the volume was 196 northbound and 151 southbound. During 1984 and 1985, the traffic volume increased by approximately 10 percent. Maldonado and Guayaquil Streets are connected to the local road network by at-grade intersections. The local streets in the historical center form a dense network with an average distance of 50 to 80 m between intersections. The streets are narrow, with sharp curves. Because parking space is limited,

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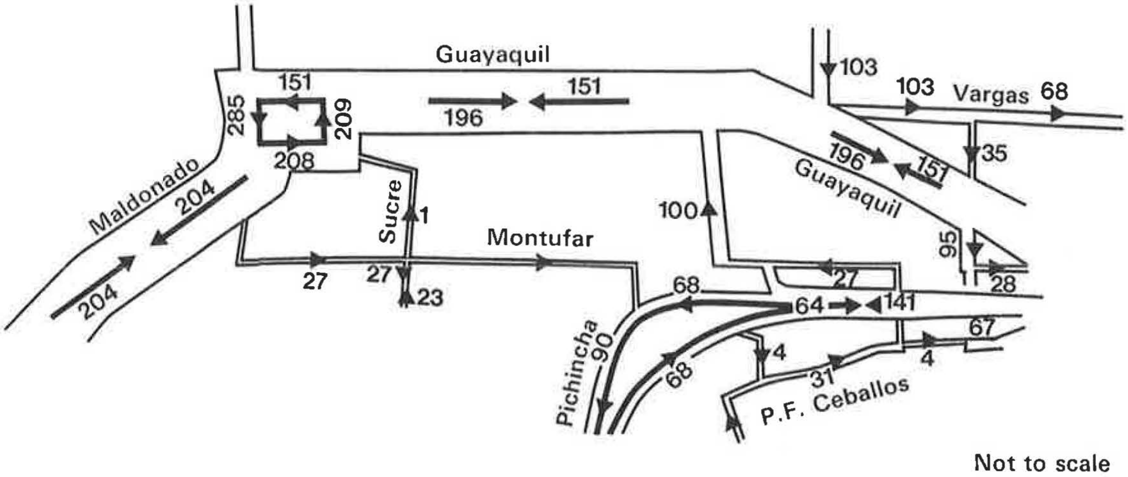

FIGURE 1 Sample flow of buses in the historical center.

illegal parking is common, causing traffic congestion and hazards.

The case study indicated that bus service did not meet the actual fluctuation in demand. In 1984 and 1985, the bus fleet in Quito included 2,031 buses, operated by 36 different owners with limited coordination; most of the buses were overloaded. The total vehicle fleet of Quito was over 100,000 at that time. The bus fleet comprised 477 large buses, 1,204 medium-sized buses (known as *colectivos*), and 350 small buses (or minibuses). The large and medium-sized buses, which have 42 and 30 seats, respectively, have already been in service for 13 to 14 years. The small buses, with 22 seats, averaged 6 years of age.

The bus system serves 81 routes in the metropolitan area. The lengths of the routes vary between 15 and 30 km, with an average length of 24 km. At the time of the study, about 95 percent of the routes entered the historical center. This concentration of bus routes is indicated in Figure 1. Along Guayaquil Street, 11 routes are in operation; one of these is Route 10, which is analyzed in a following section. The traffic survey showed that buses entered the district at a rate of 900 per hour, contributing to a high concentration of traffic in an area of only 1 km^2. Bus traffic (in 1984 and 1985) was 13.9 percent of the total traffic volume. Private cars, taxis, and commercial vehicles represented 53.2, 19.9, and 13 percent, respectively, of the total hourly traffic volume entering the historical center. The high traffic volume resulted in traffic congestion, negative environment impact from air and noise pollution, traffic hazards, and high user costs. Figure 2 shows a typical picture of traffic congestion in the historical center during rush hour and the main street of Maldonado during offpeak hours. The origin-destination (O-D) survey indicated that the number of buses outside the historical center was too low and did not match the actual local demand. The following conclusions were drawn from the performance analysis of the bus system in Quito:

- Bus schedules did not match the fluctuation in users' demand and caused increased operating costs and time delays. Assignment or scheduling was frequently changed with little or no coordination with other bus companies.
- Bus stops were not always in convenient or safe places, and bus drivers did not always load and unload passengers at assigned bus stops. This kind of operation increased traffic hazards and the number of bus stops, as well as travel times and operating costs.
- The bus fleet in Quito was old. Most of the buses had only one door for both entrance and exit and could not provide comfortable, safe, and economic service.
- The planning and monitoring of route assignments were not carried out properly. The operations among the 36 bus companies were poorly coordinated, and scheduling was not sufficiently sensitive to changes in the demand for bus transportation.

PUBLIC TRANSPORTATION SURVEY

A bus transportation survey was carried out in Quito in 1984 and 1985. The main purposes of this study were (a) to determine the demand for bus use in the entire metropolitan area, especially in the historical center; (b) to determine the relationship between the demand and the capacity of each route; and (c) to improve the operation and administration of the bus services. For the purposes of this survey, Quito was divided into 13 zones, and for each zone the following information was analyzed: number of bus users, number of trips per person per day, purpose of each trip, origin and destination (O–D) of each trip, number and location of bus transfers for each O–D, need for improvements in scheduling level of service, and the like.

The conclusions of this survey concerning the demand for bus service in Quito are shown in Figure 3. Demand is defined in terms of the number of passengers using the buses in the metropolitan area. Figure 3 shows that the daily number of passengers traveling by bus through the historical center was approximately 800,000 to 900,000, using 95 percent of the available bus fleet. However, only 280,000 passengers wanted to go there. In other words, about 65 percent of the passengers traveled through the center needlessly. To verify this conclusion, an additional and special O–D survey was carried out at bus stops only. For each passenger trip, the first and last stop were determined along with such factors as the actual bus route used, other possible routes, and the location of and need for bus transfer. The conclusions of this survey verified the previous one and indicated that (a) most of the bus transfers took place inside the historical center, (b) 65 percent of the passengers were unnecessarily routed through the center, (c) most of the passengers believed that the center was practically the only place to find a bus transfer, and (d) most of the bus routes between various O–D zones passed through the center. To complete the Quito study, a passenger count survey was carried out at representative bus stops. This survey indicated a low occupancy rate for local buses. During offpeak hours, occupancy dropped to an average of 40 to 50 percent on the busiest routes. This conclusion was confirmed by means of the revenue analysis and ticket sales.

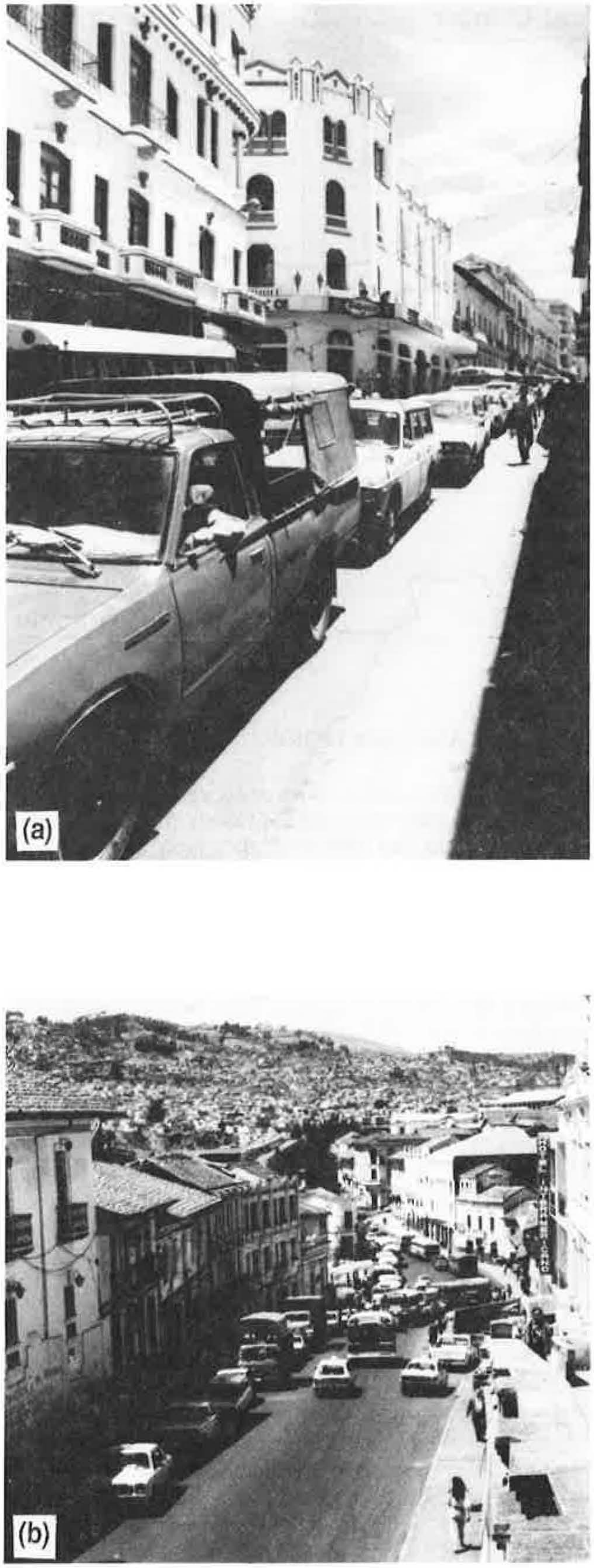
FIGURE 2 Sample of traffic flow in the historical center (a) during rush hour and (b) during offpeak hours.

IMPROVEMENT IN BUS OPERATION

The conclusions of the demand analysis were used to optimize the planning and rescheduling of the bus system. For example, Route 10 was divided into two routes, both having the same O–D. One route crossed the historical center, but the second bypassed it. Similar procedures were used to improve other routes. The result of the implementation of the new program was a 40- to 50-percent reduction in the number of buses traveling into the historical center. Travel time through the center was reduced, on average, from 10 to 8.5 min after the Route 10 change. Another improvement for meeting the fluctuation in demand optimized the use of different sizes of buses. For example, during the morning rush hour (between 7:30 and 8:30 a.m.), 25 small, 20 medium-sized, and 15 large buses were used to provide service to 1,000 passengers. These 60 buses had a capacity of 1,580 passengers. After the reorganization, 8 small, 13 medium-sized, and 10 large buses were used to serve the same number of passengers. An effort was made to maximize the use of larger buses and thus reduce the total number of buses needed to enter the historical center. After the reorganization, 31 buses could provide the service previously provided by 60.

In order to better manage the new bus planning program, a simple management information system (MIS) was developed. This MIS is now used to collect and evaluate data and to optimize the scheduling and planning of bus operations. It permits fast access to such information as the number of bus tickets sold; actual number of buses in service; rate of occupancy, mileage, and fuel consumption; and the maintenance record for each bus. The information stored in the MIS was found to be useful in predicting the fluctuation in future demand for bus services. For example, the MIS program will adjust the schedule and assignment of the bus fleet to meet the demand during an important event, such as the opening of a new school year, a sports event, or a special public ceremony. By means of the new organization, coordination, and operation of the bus industry, it was possible to reduce by 40 to 50 percent the number of buses entering the historical center. The impact of this reduction was a savings of about one-fifth of the fleet for the metropolitan area, contributing to a reduction of operating costs and permitting the use of these buses to improve other public transportation needs of Ecuador, such as those of the rural areas outside Quito.

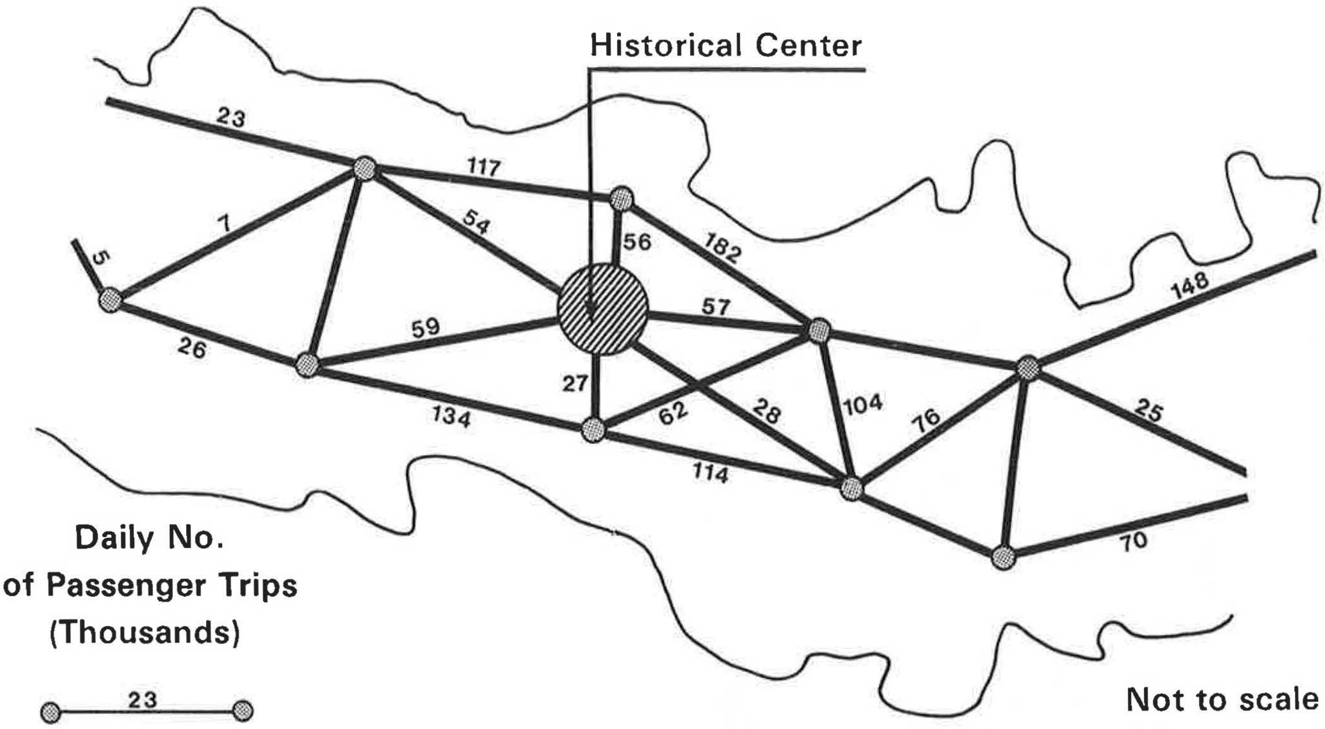

FIGURE 3 Sample demands of bus passengers in Quito.

SOCIOECONOMIC ANALYSIS

The socioeconomic benefits of an improvement in bus service can be measured in terms of an increase in passenger comfort, a reduction in the number and severity of accidents, and a reduction in user costs and traveling time. The 1984–1985 value of the used 2,031-vehicle bus fleet in Quito was approximately $40 million (all values in U.S. dollars). The value of a new bus fleet would be $200 million. Because one-fifth of the present fleet was saved for other uses, the economic value of this benefit could be set at $8 million.

Another economic benefit was obtained from the reduction of travel time inside the historical center from 10 to 6 min. This time reduction translated to an hourly savings of 60 bus-hours during the peak hour or a daily saving of 600 bus-hours, equivalent to a daily savings of approximately $3,600 or an annual savings of $1.3 million. This benefit is related only to the reduction of bus operating costs; it does not include the value of passenger time savings. These savings were estimated at 4,000 work-hours per day, or an annual savings of approximately $1.2 million. It was also found that because of the improvement in the bus service and its reliability, the daily number of users traveling into the historical center increased by 80,000 persons (approximately 10 percent of the total daily number of passengers). In other words, the bus service became more attractive to the public after the reorganization.

After the reorganization, the administrative costs were reduced by an estimated $250,000 per year. These savings were obtained by using the MIS program, which permitted a reduction in the labor needed for supervision, control, and monitoring. The total annual cost savings of the bus transportation industry was estimated in 1985 at $10 to $11 million, or approximately 25 percent of the present value of Quito's bus fleet.

SUMMARY AND CONCLUSIONS

The bus fleet in Quito was owned and operated by 36 different organizations, companies, and individuals. The total number of buses in 1984 and 1985 was 2,031, most of which were overused. Of this fleet, 477 were large (42 seats), 1,204 were medium-sized (30 seats), and 350 were small (22 seats). This bus system served 81 routes in the metropolitan area, and 95 percent of the routes crossed the historical center of the city.

The area of the historical center is 1 km^2, and a traffic study indicated that 900 buses per hour were entering the district, resulting in high traffic congestion, air and noise pollution, traffic hazards, and high user costs.

The Quito study indicated the following deficiencies in bus service: bus schedules did not meet the actual fluctuation in passenger demand, bus stops were not always in convenient or safe places, and the planning and monitoring of route assignments were not carried out properly.

The daily number of passengers traveling by bus through the historical center was 800,000 to 900,000, using 95 percent of the city's available bus fleet. Nevertheless, only 280,000 passengers actually wanted to go to the area. In other words, about 65 percent of the passengers were forced to travel through the center to other destinations.

A new planning and bus scheduling program was implemented to improve the quality of bus service. The result of this program was a 40- to 50-percent reduction in the number of buses traveling into the historical center. Another operational improvement in matching the fluctuation in demand was obtained by optimizing the use of different sizes of buses. The use of fewer and larger buses reduced both volume of traffic and travel time. Reducing and relocating the bus stops also reduced travel time. After the implementation of the new planning and operation program, travel time was reduced from 10 to 6 min, and the probability of a bus arriving on schedule, plus or minus 2 min, was increased from 30 percent to 75 percent.

The reduction of travel time and the improvement of bus services increased ridership in the central district by approximately 10 percent. No significant change in ridership was observed outside the historical center during the 1 to 2 years of traffic monitoring.

The implementation of the new bus planning program was aided by enforcing new traffic and parking regulations. Merchandising was removed from main streets, and bus lanes were established. The parking system was reorganized, and a new system of tariffs and time limits was enforced.

The socioeconomic benefits of the improvement in bus service were measured in terms of increased passenger comfort, reduction in the number and severity of accidents, and reduction of operating costs. The value of Quito's bus fleet in 1984 and 1985 was approximately $40 million. It was estimated that approximately 25 percent of this value was saved by implementing the new bus planning and operating program.

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Bus Maintenance Performance: Findings and Direction for Research

BRUCE A. LEDERER AND LITTLETON C. MACDORMAN

Some performance indicators may be used to identify transit systems with superior bus maintenance performance. A literature review was conducted to identify factors often reported as affecting maintenance performance. A data base was created using all of the reported factors available in the 1984 UMTA Section 15 information. Analyses using the data base were conducted to design performance indicators and peer groups of transit systems. Within each of the peer groups, transit systems with superior bus maintenance performance were identified. The methodological procedures used for this paper were modeled on the approach used by Fielding in work for UMTA to develop indicators and peer groups for overall transit performance analysis. This work (like Fielding's) was limited by the lack of a comprehensive data base from which to extract significant information relevant to the research. For example, the absence of climatic and topographic data may make the natural groupings of peer transit systems suspect to maintenance experts. Additionally, much information on the effectiveness performance or quality of maintenance work was also absent. Such limitations may have a direct bearing on the validity and industry acceptance of the results, so the following actions are recommended: (a) adopt the methodological procedures of this paper and extend the data base to include the data not found in UMTA Section 15 that are believed to be important to bus maintenance performance and (b) on the basis of the results of an evaluation using the revised data base, select several systems with high performance and several systems with low performance and conduct field audits to identify the causes of their performance differences. Using the results of the field audits, prepare guidelines that document the procedures and practices of superior bus maintenance programs. If the resources of transit systems are to be protected and preserved, it is important to implement the recommendations. The results will assist transit systems to identify deficiencies within their own program and to achieve superior maintenance performance.

As public transportation funding becomes scarcer, many transit managers and funding institutions are asking how to preserve and increase the productive life of their fleets. The answer is maintenance: on this answer have followed systematic efforts to determine the efficiency and effectiveness of transit systems' maintenance performance and to identify successful maintenance programs. UMTA sponsored a study (*1*) that addressed these issues. The study was intended to

- Determine which maintenance performance indicators best identify transit systems with superior motor bus maintenance performance, and
- Identify peer groups for transit systems to analyze maintenance performance.

RELEVANT ISSUES

Maintenance performance is critically important to all transit systems. The goal of transit vehicle maintenance is to efficiently provide clean, comfortable, safe, and reliable vehicles in accordance with the service demands of the transit system (essentially the demands of the transportation function for scheduled and unscheduled service).

Despite the importance of maintenance performance, the literature review (Appendix A) revealed that relatively little research has been conducted to identify superior maintenance performance or to group transit systems on the basis of the success of their maintenance programs. Given the state of work in the field, this study was unusually ambitious and confronted several difficulties. There is no consensus on how to quantify superior maintenance performance; the data required are extensive and in many cases not available in secondary sources. Research assumptions in the field are vague and sometimes contradictory in two principal areas: "What is superior maintenance performance?" and "What factors affect maintenance performance?"

What is Superior Maintenance Performance?

Transit maintenance performance can be evaluated according to at least two criteria:

- Effectiveness, an ability to deliver or provide quality services to meet public transportation needs and attract riders, and
- Efficiency, the amount of service produced for the resources (labor, materials, supplies) expended.

Although most maintenance managers and analysts agree on these two criteria, there is little agreement on specific aspects of maintenance performance. The following areas of performance must be considered:

- Safety,
- Reliability,
- Comfort,
- Cleanliness,
- Appearance, and
- Economy.

Transit systems generally have different standards for each of these areas of performance and often use different definitions. How clean is clean? How reliable (or safe) is very

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reliable (or safe): when is a transit vehicle unreliable, unsafe, or uncomfortable? Each of these questions addresses the quality of transit maintenance and may be considered in evaluating the effectiveness of a vehicle maintenance program.

Economy, the last area of performance listed, may include the total expenses of vehicle maintenance, maintenance labor expense, the number of maintenance employees (or mechanics), the number of hours expended by maintenance employees, and the expense of maintenance materials, services, and supplies. Economy is considered in evaluating maintenance efficiency (use of resources), which, although somewhat easier than evaluating maintenance effectiveness (i.e., quality issues), is still complex. The evaluator must consider the possibility that less preventive maintenance or fewer vehicle overhauls impact service quality and ultimately shorten the useful life of the fleet, thus requiring greater capital investments.

Although maintenance managers are responsible for and concerned about the performance of vehicle maintenance, various consumer groups ultimately judge the efficiency and effectiveness of a maintenance department's efforts. These groups include transit system executives and managers, bus operators, and the riding public. Each of these groups may have different standards for the areas of performance listed above. In short, there is little agreement on the characteristics of superior maintenance performance, for effectiveness or efficiency.

What Factors Affect Maintenance Performance?

At least seven categories of factors affect maintenance performance, influencing the type, frequency, and cost of vehicle maintenance requirements. These categories are included in the following list. Many other items in these categories may affect maintenance performance or allow for peer groupings of systems—the following items are illustrative only.

- *Fleet characteristics.* The type and number of active, spare, and inactive vehicles; fleet age; fleet size and weight; mix of vehicle manufacturers; fuel grade and type; and vehicle amenities (i.e., air conditioning and wheelchair lifts).
- *Vehicle operating environment.* Weather, topography, traffic congestion, ridership levels, roadway conditions, and other service area characteristics.
- *Vehicle maintenance work force characteristics.* Size, seniority, skill or competence level, work hours (straight and overtime), nonwork hours (benefit and absence), available training programs, and turnover.
- *Employee work conditions.* Work area (heating, ventilation, lighting, size, configuration, crowding, and age); maintenance supervision (level, skill, and competence); and availability of parts, inventory, equipment, and tools.
- *Maintenance management.* Policies and practices pertaining to performance, preventive maintenance, pre- and post-run inspections, cleanliness and safety inspections, work shifts, management information system (data adequacy and accessibility), training, and union-management relations.
- *Labor agreement.* Provisions and work rules resulting from collective bargaining that may affect the efficiency and productivity of maintenance operations.
- *Other.* Adequacy or abundance of funding from federal, state, and local sources.

In many cases, these factors are local, dependent on a particular environment or reflecting decisions made by transit management or boards that cannot be changed immediately. For this paper, only nonlocal factors that cut across all systems were used to distinguish maintenance performance.

MAINTENANCE DATA AND INDICATORS

Important first steps in the study were to identify the data needed to measure maintenance performance and to define meaningful peer groups for performance comparison. This effort required the collection of certain information about transit systems and their operating environments. First, the data ideally needed to evaluate maintenance performance were identified; next, the general availability of these data was researched. Availability and cost to obtain data determined which items were included in the data base.

Statistics To Analyze Maintenance Performance

Data in the following categories can be used to describe and measure maintenance performance:

- *Resource inputs.* The resources expended to perform vehicle maintenance include labor, capital, material, services, and other measurable items and may be classified as financial or nonfinancial.
- *Service outputs.* These nonfinancial operating results of resource expenditures may be numerical measures, such as miles or hours of services, or quality statistics, such as number of accidents, roadcalls, delays, or measured cleanliness.
- *Customer results.* The actual results of service outputs may be expressed in consumption or customer impact terms. For example, this measure may include the number of passenger or operator complaints, injuries or fatalities due to mechanical failures, or passenger-trips or passenger-miles.

Data elements for these categories initially considered were the following.

Resource Inputs

- Vehicle maintenance expense,
- Vehicle maintenance labor expense,
- Vehicle mechanic labor expense,
- Vehicle maintenance employee work-hours,
- Vehicle mechanic work-hours,
- Vehicle maintenance employees,
- Vehicle mechanics,
- Inspection and maintenance hours,
- Vehicle maintenance material expense,
- Fuel consumed, and
- Active vehicles.

Service Outputs

- Vehicle revenue-miles,
- Vehicle revenue-hours,

- Vehicle-miles,
- Vehicle-hours,
- Peak vehicles or vehicles operated in maximum service,
- Base vehicles,
- Mechanical roadcalls,
- Other mechanical failures,
- Revenue-hours lost to mechanical failures,
- Missed pullouts because of mechanical failures,
- Late pullouts because of mechanical failures, and
- Number of collision accidents.

Customer Results

- Passenger complaints because of mechanical failures,
- Passenger fatalities and injuries because of mechanical failures,
- Driver complaints or comments,
- Passenger-trips, and
- Passenger-miles.

Data Availability

Data useful in evaluating transit maintenance performance can be found in primary and secondary transit industry and nontransit industry sources.

- *Primary transit industry data.* Data are available directly from all transit systems, in records, reports, and interviews. These primary sources produce the most detailed, up-to-date, and complete information.
- *Secondary transit industry data.* Transit system data are also available through the UMTA Section 15 data base, a secondary source published annually and recorded on tapes. The U.S. Department of Transportation maintains a more extensive Section 15 data base.
- *Primary and secondary nontransit industry data.* Data that may be used to evaluate transit maintenance performance are also available from sources other than transit systems. These primary and secondary sources may require surveying local communities to determine distinguishing characteristics of the transit operating environment or researching documents that report on topography, weather, or roadway conditions. These data could be best used to identify peer groupings for transit systems.

Data Base Development

Clearly, the most detailed source of data on transit performance is individual transit systems. Collecting these data from transit systems would have produced a rich data base, but the expense was prohibitive under the terms of this study. The Section 15 data base of the U.S. Department of Transportation included statistics pertaining to a number of factors in transit maintenance performance. Although it did not contain all the information desired for this study, this data base is a recognized source of uniform transit data; it was used because time and the funds for this study did not permit the use of either primary transit industry data or nontransit industry data.

The Section 15 data base included selected data for 1984 on fleet characteristics, vehicle operating environment, resource inputs, and service outputs. The data base included data in all categories but was not exhaustive in any category. This data base has a uniform structure and format, which permit the merging of different data elements to create data bases for particular purposes. The following UMTA Section 15 data elements were included in the bus maintenance data base for this study:

- Transit system identification number;
- Year being examined;
- Urbanized area number;
- Vehicles operated in maximum service;
- Number of roadcalls, mechanical failure;
- Number of roadcalls, other reasons;
- Total roadcalls;
- Labor-hours for inspection and maintenance;
- Total number of light maintenance facilities;
- Maintenance employees, executive/professional/supervisory;
- Maintenance employees, support;
- Maintenance employees, review vehicle maintenance mechanics;
- Maintenance employees, other maintenance mechanics;
- Maintenance employees, vehicle service persons;
- Number of accidents, collision;
- Number of accidents, noncollision;
- Number of accidents, station;
- Annual vehicle-miles (thousands);
- Annual vehicle-hours (thousands);
- Annual unlinked passenger trips (thousands);
- Annual passenger miles (thousands);
- Maximum number of vehicles operated in average base period;
- Total operating expenses ($ thousands);
- Vehicle maintenance expense;
- Materials and supplies: fuel and lubrication;
- Materials and supplies: tires and others;
- Total active fleet;
- Average age of fleet (years);
- Gallons of diesel fuel (thousands);
- Gallons of gasoline (thousands);
- Gallons of LPG/LNG (thousands);
- Gallons of bunker fuel (thousands);
- Kilowatt-hours of power (thousands);
- Name of the transit system;
- City location of transit system;
- State location of transit system; and
- Mode of operation.

Data Validation

Analyzing public transportation performance using Section 15 data requires that the data be reviewed and checked, since data validity is especially important. Although uniform definitions for each Section 15 data item exist, data validation procedures were found to be necessary. Transit systems nationally continue to experience reporting errors that reflect misinterpretations of data definitions, new staff's lack of familiarity with the reporting requirements, and continuations of past reporting practices. These errors needed to be identified and resolved as much as possible to meaningfully evaluate transit performance. Often, reporting errors are not identified until an analysis is complete and inaccurate conclusions have been drawn.

Section 15 transit system financial and operating data were reviewed in a number of different ways. Individual statistics were examined, as were performance indicators. Although validation procedures cannot ensure that all data are accurate, they can screen the data and identify questionable items. The data validation procedures used in this project included statistical tests and screening tests.

Statistical tests were performed to identify outlying data that did not fit generally within the standard normal curve. The statistical tests included calculating the standard deviation, means, minimum, maximum, skewness, and kurtosis of the data. In those instances in which the data were out of the specified ranges, the suspect data (not the entire system) were removed from the data base. Previous experience with transit data has demonstrated that it generally fits within a normal distribution.

Screening tests were performed using a battery of 25 validation tests. The screens included acceptable ranges in which the data should fall to be included in the data base. Again, if data fell out of these ranges, the suspect data were removed, not the entire system.

STRUCTURING PERFORMANCE INDICATORS

Vehicle maintenance is important to public transportation service. The vehicle maintenance function affects not only the overall efficiency of transit operations, but the quality and effectiveness of a system's service. As performance evaluation procedures have evolved in the public transportation industry, three general measures have proven useful to public officials, system managers, and researchers. These measures were identified by Fielding (*2*) as

- Cost-effectiveness,
- Service effectiveness, and
- Resource efficiency.

Performance Indicator Definitions

Fielding (*2*) defined the performance measure of cost-effectiveness as the consumption of public transportation services in relation to the resources expended. An evaluation of these measures attempts to answer the question, "How much public transportation service is used or passenger revenue is received per dollar or resource expended?" Consumption is measured by passenger trips or revenue received, and costs are measured in terms of resources expended to produce the public transportation service. The more passengers carried or revenues received in relation to resources expended, the more cost-effective the service.

Service effectiveness is defined as the consumption of public transportation service in relation to the amount of service available. An analysis of these measures attempts to answer the question, "How much public transportation service is consumed (or revenue received), at an established fare, in relation to the amount of service available?" The more service consumption (or passenger revenue) in relation to service output or availability, the higher the level of service effectiveness. Factors reflecting service quality and influencing the use of and perceptions about public transportation services by the public are important elements of service effectiveness. An analysis of service quality indicators may show how available, reliable, attractive, safe, and comfortable the public transportation services are. In many respects, these issues are less easily quantified and measured than other performance areas.

Resource efficiency is the amount of public transportation service produced for the community in relation to the resources expended. An analysis of these measures attempts to answer the question, "How much public transportation service is produced per dollar of resource expended?" Amounts of service produced are measured in terms of service outputs, such as vehicle hours or vehicle miles. Resources expended include labor, capital, materials, and services. The more service produced per resource expended, the greater the resource efficiency of the public transportation service.

Fielding's (*2*) performance concept was used to structure indicators to evaluate vehicle maintenance performance for this paper. This evaluation focused on key vehicle maintenance performance indicators, which measure resource efficiency and service effectiveness. While cost-effectiveness indicators may be more important to an overall performance evaluation than either resource efficiency or service effectiveness indicators, cost-effectiveness indicators were not developed to analyze vehicle maintenance performance, because the maintenance function only partially contributes, albeit importantly, to the overall performance of public transportation service.

The list of indicators that were considered to measure the vehicle maintenance performance of U.S. bus transit systems follows.

Resource Efficiency

- Total vehicle-miles per dollar of vehicle maintenance expense,
- Total vehicle-hours per dollar of vehicle maintenance expense,
- Vehicles operated in maximum service per dollar of vehicle maintenance expense,
- Total vehicle-miles per inspection and maintenance labor hours,
- Total vehicle-hours per inspection and maintenance labor hours,
- Vehicles operated in maximum service per inspection and maintenance labor hours, and
- Total vehicle-miles per gallon of fuel.

Service Effectiveness

- Total passenger trips per mechanical roadcall,
- Total passenger-miles per mechanical roadcall, and
- Total vehicle-miles per mechanical roadcall.

The list was limited by the availability of data in the 1984 UMTA Section 15 annual report. Data limitations handicapped the study, especially in evaluating the quality and effectiveness of vehicle maintenance performance. In addition, roadcall incident data in the Section 15 report have historically been considered suspect because of definitional problems.

Vehicle-miles per mechanical roadcall is a service effectiveness indicator. This indicator is, in fact, a performance descriptor, because it measures neither the efficiency nor the effectiveness of vehicle maintenance performance. However, because there is a lack of maintenance quality statistics in the UMTA Section 15 report and because the descriptor has long been used by the transit industry as a measure of maintenance proficiency, it was included. Had other data on the quality or effectiveness of vehicle maintenance performance been available, they might have been used in lieu of the performance measure vehicle-miles per mechanical roadcall.

Identifying Key Indicators

Fielding (*1*) identified several candidate vehicle maintenance performance indicators. Making his decision on the basis of 1980 UMTA Section 15 data, Fielding omitted all indicators that included roadcalls, passenger miles, and fuel data because of perceived reliability and definitional problems. On the basis of a principal components analysis, Fielding concluded that total vehicle-miles per maintenance employee and peak vehicles per maintenance employee were the best available indicators to measure vehicle maintenance efficiency. He reported no vehicle maintenance service effectiveness indicators.

This study applied 1984 UMTA Section 15 data, which is considered more reliable than the 1980 data used by Fielding (*1*), although roadcalls and employee count data are still considered to be inconsistent by many researchers. Because the focus of the study was vehicle maintenance and not total system performance, resource efficiency and service effectiveness indicators were included after an independent validation of the data was conducted to remove as many suspect values from the data base as possible.

A type of multivariate or factor analysis called principal components analysis (PCA) was conducted to reduce many measures and ratios to those few that statistically explain high percentages of performance variance (*1*). There are two main types of factor analysis: PCA and inferential or classical factor analysis. PCA assumes that the entire population of cases—not a sample—is analyzed. Analytical solutions describe the data at hand and the relationships among the variables as represented in the input data. Inferential factor analysis adjusts analytical solutions to make predictions about a larger, ideal population. Because the entire population of motor bus systems was represented in the data base, and because one objective of this study was to identify relevent groupings of systems, the use of PCA was considered appropriate (*1*).

The PCA of both resource efficiency and service effectiveness indicators identified those indicators whose variability best reflected the vehicle maintenance performance of bus transit systems. Resource efficiency performance was best described in the following key indicators:

- Vehicle-miles per dollar of vehicle maintenance expense (40.5 percent) and
- Vehicle-miles per inspection and maintenance labor hour (38.3 percent).

Service effectiveness performance was best described by the following indicators:

- Passenger-miles per mechanical roadcall (36.6 percent) and
- Vehicle-miles per mechanical roadcall (35.5 percent).

The values contained in the parentheses after each performance indicator represent the percent of total variability explained by the indicator in the final principal components analysis.

Comparison of performance among transit systems over time is best accomplished by a comparison of similar transit systems. Analysts and policy makers can be misled by comparing the performances of transit systems that are essentially unlike. Comparisons can be more meaningful when peer groups of transit systems are identified. In addition, the relationship of operating characteristics and performance can be examined by focusing on differences in performance across peer groups with different operating characteristics. Finally, transit industry changes over time can be evaluated in relation to operating characteristics of the transit systems (*1*).

An important objective was to identify factors or variables on which to base a stratification of transit systems into vehicle maintenance peer groups. Again, PCA was used to identify those factors that statistically explained high percentages of variance among the transit systems. Such factors may include transit system characteristics and factors external to transit systems, such as weather and topography.

Selecting Topology Variables

Topology variables are factors that may be used to separate transit systems into groups to conduct analyses such as maintenance performance analysis. Topology variables may also be used to periodically classify or reclassify transit systems. Such variables, previously described, include fleet characteristics, vehicle operating environments, maintenance work force characteristics, employee work place conditions, maintenance management policies and procedures, and labor agreement provisions and work rules. The data available for analysis and the selection of topology variables were limited to the information available from Tables 2 and 3 of the *1984 UMTA Section 15 Annual Report*. This data limitation is important, because it ultimately affected the validity of results produced from this study.

The following list of variables or factors was initially considered to develop the vehicle maintenance topology:

- Total vehicle-miles per vehicle-hour,
- Vehicles operated in maximum service per vehicle operated in base service,
- Total vehicle-hours per vehicle operated in maximum service,
- Total vehicle-miles per vehicle operated in maximum service,
- Total passenger-miles per vehicle-miles,

- Average fleet age,
- Total vehicle-miles per collision accident,
- Total vehicle-miles,
- Total vehicle-hours,
- Total vehicles operated in maximum service,
- Total active fleet, and
- Total active fleet per vehicle operated in maximum service.

A principal components analysis revealed that several of these variables were highly correlated (e.g., vehicle-miles and vehicle-hours). Although the analysis identified patterns of variable equality, the final set of variables was selected on the basis of the perceived quality and availability of bus maintenance statistics. The variables selected for use were

- Total annual vehicle-miles (16.8 percent),
- Average active fleet years of age (16.6 percent),
- Total annual vehicle-miles per vehicle operated in maximum service (16.8 percent), and
- Total annual vehicle-miles per collision accident (16.7 percent).

The values contained in the parentheses after each factor represent the percent of total variability explained by the variable in the final PCA. The low percentages found here indicate that no factors were overwhelmingly significant in explaining the underlying topological structure.

The final set of topology variables did not include many external factors that may affect vehicle maintenance performance. For example, weather, climate, and topography were not included because the data were not readily available. The following variables were selected:

- *Total annual vehicle-miles.* This variable captures the magnitude of the transit system's overall operation and, therefore, its maintenance needs. It tends to distinguish between larger and smaller systems, where collective bargaining provisions and work rules may affect performance.
- *Average active fleet years of age.* This variable distinguishes between transit systems with older equipment, which may cause problems because of fatigue, and systems with newer but perhaps more complex equipment.
- *Total annual vehicle-miles per vehicle operated in maximum service.* This variable distinguishes system fleets that are heavily used from those that are less used. Vehicles may be heavily used because of relatively high operating speeds, low peak-to-base service ratios, or longer periods of daily service operation. Lower average vehicle use may result from relatively high peak-to-base service ratios, lower operating speeds, or shorter periods of daily service operation.
- *Total annual vehicle-miles per collision accident.* This variable identifies transit systems that are experiencing accident rates causing vehicle maintenance expenditures that are higher or lower than average, which affects resource efficiency performance.

Developing Maintenance Peer Groups

One of the final objectives was to identify groups of transit systems that operate in similar vehicle maintenance performance environments. Using the best stratifiers, a cluster analysis was conducted. This analysis used complete or average linkage algorithms to develop dendograms, which in turn were used to develop appropriate peer groups.

Cluster analysis is a general term referring to a large number of procedures that have in common the goal of constructing groups of items (either data items or variables) on the basis of their similarity across a profile of observations. The result of a cluster analysis is the formation of a number of groups of items and the assignment of each item to one of these groups.

Cluster analysis and similar data grouping techniques differ from methods such as discriminant analysis, which attempts to classify objects into known groups. Such analyses require that the groups be known in advance, whereas cluster analysis constructs the groups.

Dendograms were used to develop peer groupings of transit systems on the basis of the variables or stratifiers that best explained vehicle maintenance performance variability.

The centroid method of cluster analysis was employed to identify bus maintenance peer groups. The four selected topology variables of each transit system were standardized to Z-scores, and the closeness of transit systems was measured using the Euclidian distance between their locations. After several trials, 21 clusters were identified, with the largest cluster containing 84 transit systems and the smallest cluster containing just 2 systems.

An analysis of variance (ANOVA) test was used to determine whether each of the 21 identified transit clusters was significantly different from all others or was part of a larger combination of clusters. The ANOVA test was conducted using the four previously identified maintenance performance measures of resource efficiency and service effectiveness.

If there was no significant statistical difference ($p \geq 0.10$) in any of the four performance indicators between each cluster pair, then the pair would be combined into a single peer group. This procedure was continued until all clusters were statistically different. The number of clusters was reduced from 21 to 8. The final bus maintenance topology tree is shown in Figure 1.

Table 1 presents statistical information about the performance values for each of the eight peer groups. Each 1984 peer group is briefly described in the following paragraphs.

Group A contains 52 bus systems, each operating fewer than 1.1 million veh-mi annually with a fleet whose average age is less than 12 years. Group A bus fleets have relatively low use and below-average safety records. Both vehicle maintenance resource efficiency and service effectiveness performance are above average.

Group B contains 110 bus systems, each operating fewer than 12 million veh-mi annually with a fleet whose average age is generally less than 12 years. Group B bus fleets have relatively high use and good safety records. Their resource efficiency performance is above average. Although the average rate of roadcalls is low, passenger miles are also low, making their service effectiveness performance average.

Group C contains 27 bus systems, each operating between 1.1 and 12 million veh-mi annually. The average age of the fleets is less than 7 years, and they have below-average use. The Group C vehicle maintenance performance is considered average.

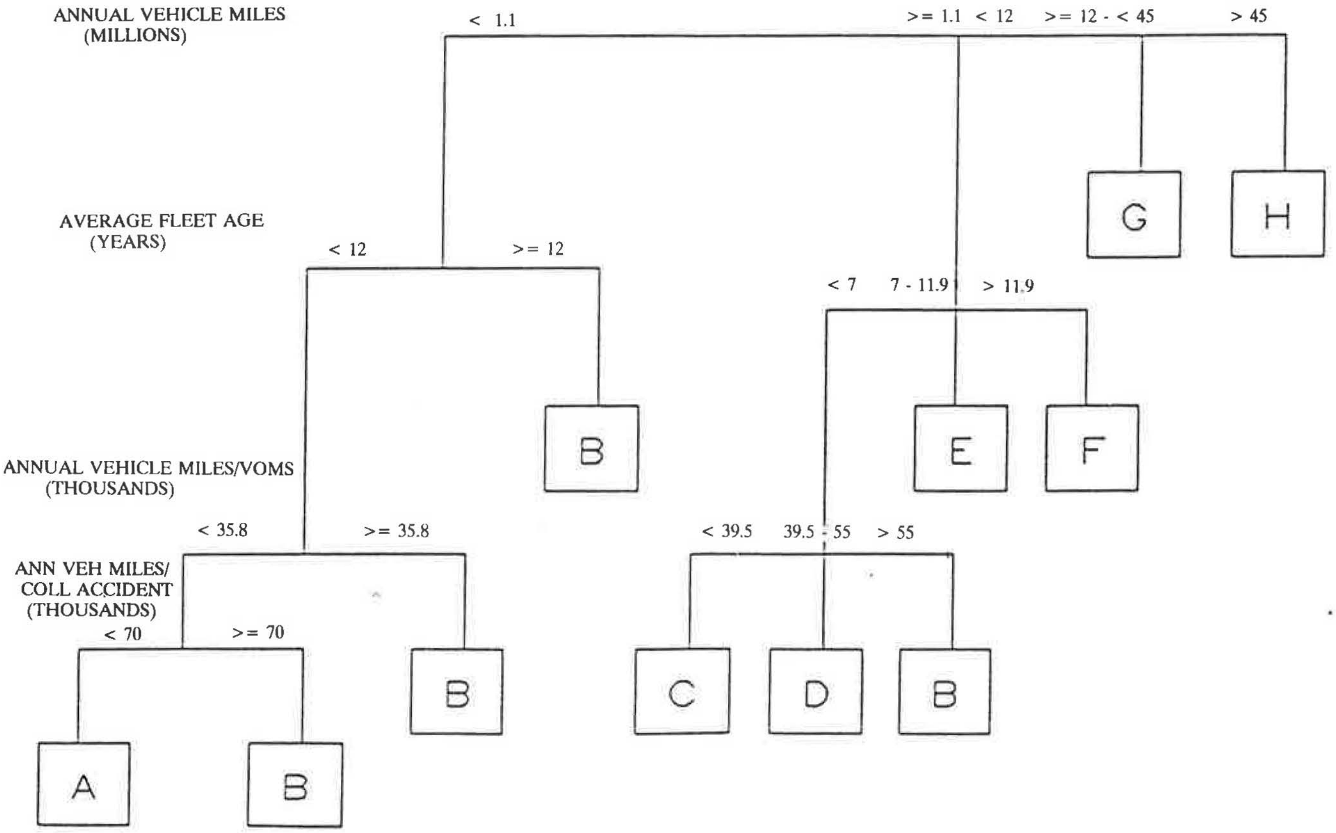

FIGURE 1 Bus maintenance topology tree.

Group D contains 24 bus systems, each operating between 1.1 and 12 million veh-mi annually. The average fleet age is less than 7 years, and vehicle use is average. Their resource efficiency performance is above average, while their service effectiveness performance is average.

Group E contains 79 bus systems, each operating between 1.1 and 12 million veh-mi annually. The average fleet age is between 7 and 11.9 years. Both resource efficiency and service effectiveness performance are average to below average.

Group F contains 14 bus systems, each operating between 1.1 and 12 million veh-mi annually. This group is distinguished by its average fleet age, which is equal to or greater than 11.9 years of age. Their resource efficiency performance is below average, and their service effectiveness is average to below average.

Group G contains 23 bus systems, each operating between 12 and 45 million veh-mi annually. These are bus systems operating in the larger urbanized areas of the United States. Their performance is characterized by both low resource efficiency and low service effectiveness.

Group H contains 5 bus systems operating in the larger to largest urbanized areas of the United States. Their resource efficiency performance is the lowest of any peer group, but their service effectiveness performance is above average, because their high passenger-miles overcome a lower-than-average rate of roadcalls per mile.

CONCLUSIONS AND RECOMMENDATIONS

The primary objective was to identify performance indicators that may be used to identify transit systems with superior bus maintenance performance. A literature review was conducted to identify factors often reported as affecting maintenance performance. A data base was created using all of the reported factors available in the 1984 UMTA Section 15 information. Analyses using the data base were conducted to design performance indicators and peer groups of transit systems. Within each peer group, transit systems with superior bus maintenance performance were identified. The remainder of this section contains the conclusions and recommendations resulting from these analyses.

The methodological procedures used here were based on the approach used by Fielding (*2*) in his work for UMTA to develop indicators and peer groups for overall transit performance analysis. Several approaches are possible and were considered to achieve the study's objectives; the procedures used are considered sound and appropriate given the resources available. The report to UMTA (*1*) identified the names of the transit systems that were most resource efficient and service effective by peer group, but it would be premature to present these systems here. This study's work (as was Fielding's) was limited by the lack of a comprehensive data base from which to extract significant information relevant to the

TABLE 1 STATISTICAL CHARACTERISTICS OF PERFORMANCE INDICATORS FOR BUS MAINTENANCE PEER GROUPS

PEER GROUP	STATISTICAL CHARACTERISTIC	VEH MILES / VEH MAINT $	VEH MILES / INSPEC & LABOR HOUR	PASS MILES / MECH RDCL	VEH MILES / MECH RDCL
A	Count	52	50	48	52
	Min	0.97	13.1	1921	1310
	Max	4.53	185.0	645600	128533
	Mean	2.43	66.1	112104	20242
	SD	0.92	33.9	148932	25492
B	Count	109	104	103	110
	Min	0.90	23.9	2173	833
	Max	6.38	526.7	297000	92140
	Mean	2.83	54.9	44712	12079
	SD	1.14	68.9	52488	17066
C	Count	27	25	22	24
	Min	1.07	28.3	9468	1210
	Max	3.37	89.7	285388	33240
	Mean	1.94	54.9	62882	7077
	SD	0.60	16.3	77606	7664
D	Count	23	23	19	24
	Min	1.15	48.8	9897	1293
	Max	3.90	292.3	173662	17633
	Mean	2.44	99.7	49494	5331
	SD	0.64	48.8	44338	3991
E	Count	79	71	70	79
	Min	0.55	19.8	663	246
	Max	5.02	266.5	383493	25706
	Mean	2.06	68.5	45149	5049
	SD	0.72	39.0	52301	4325
F	Count	14	12	13	14
	Min	0.86	19.4	9617	630
	Max	2.34	95.4	155153	44721
	Mean	1.57	45.8	40162	7467
	SD	0.46	21.2	36930	11436
G	Count	23	22	20	22
	Min	0.83	22.8	11817	991
	Max	2.29	81.7	92702	6015
	Mean	1.35	49.3	32162	2973
	SD	0.38	15.1	19736	1465
H	Count	5	5	5	5
	Min	0.55	13.5	27622	1108
	Max	1.37	49.7	128825	7115
	Mean	0.98	33.6	61903	3612
	SD	0.26	12.3	37458	2177

research. Such limitations may have a direct bearing on the validity and industry acceptance of the results.

On the basis of these conclusions, the following recommendations are made:

- Use the methodological procedures of this study and extend the data base to include data believed to be important to bus maintenance performance but not found in UMTA Section 15. This extension of the data base may result in different maintenance performance indicators, topology variables, and peer group structure.
- Identify bus transit systems, by peer group, whose maintenance performance is characterized by the recommended methodology to be superior (i.e., resource efficient and service effective). In addition, identify bus transit systems, by peer group, whose maintenance performance is characterized by the recommended methodology to be inferior.
- Conduct onsite maintenance performance audits. These field audits must be comprehensive enough to include all of the factors that affect maintenance performance (as previously described) and must be focused on identifying the principal underlying causes of superior or inferior performance.
- Prepare guidelines that document the procedures and practices of superior bus maintenance programs.

Finally, if the resources of bus transit systems are to be protected and preserved, it is important to implement the study recommendations. The results will assist transit systems to identify deficiencies within their own program and to achieve superior maintenance performance.

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PART 5

Rail Transit Operations

Toward a Passenger-Oriented Model of Subway Performance

GARY HENDERSON, HEBA ADKINS, AND PHILIP KWONG

On-time performance measures used by transportation operating agencies typically use definitions, procedures, and report formats that represent an operational rather than passenger-oriented perspective. Although providing a useful barometer of operational effectiveness, such systems only indirectly measure the passengers' experience of service. Using a random sampling methodology to construct a computerized data base of about 50,000 morning rush hour subway trains, the subway performance model developed by New York State's Metropolitan Transportation Authority Inspector General's Office is designed to measure service as subway passengers experience it. The system focuses on actual, not scheduled, service; it measures aspects of service most meaningful to riders, in terms they can relate to, and on a scale experienced by passengers. Measuring performance according to this principle affects every aspect of research design and analysis, including the selection of measurement points, the definition of a trip and a route, the time periods used, the scale of analysis (system, route, or more detailed), and the statistics to be reported. The basic concept also entails a reconsideration of the way train cancellations, bypasses, service adjustments, extra service, and headway irregularities are treated in measuring on-time performance. Features of the methodology resolve many of these analytical issues, while presenting numerous avenues for further research and development.

Transit agencies typically produce performance measures for two distinct purposes. Some statistics are calculated for internal, operational purposes, while others are produced for public reporting. There is considerable overlap and tension between these two directions. Measures are often amalgams of the two aims. Statistics produced from the perspective of transit operations are often useful for public reporting, particularly to oversight agencies and legislative bodies. Similarly, statistics produced from the public's or passenger's perspective are also useful for internal diagnostic purposes and strategic management goals.

A conceptual approach to measuring performance is being developed by the New York State Metropolitan Transportation Authority's Inspector General's Office (MTA–IG). The MTA–IG's approach to on-time performance is contrasted with the measurement system currently used by the New York City Transit Authority (NYCTA). Because there are about 3.7 million passengers riding the New York subway system each weekday, the passengers' perspective is considered. Although statistics cannot describe the experience of every passenger, the MTA–IG model provides an analytical framework to distinguish between discrete groups of passengers when calculating on-time performance.

A simple example of the difference between the operational and passenger perspectives is the calculation of the delay that occurs when a train breaks down between stations. From the operational perspective, the delay is over once the passengers are discharged and the disabled train departs. For the riders, the delay is over when they board another train.

NYCTA performance measures at present do not meet the requirements of a passenger-oriented model. For example, they focus on the percentage of trains arriving on time, not on the percentage of passengers arriving at their destinations on time. In many cases, train arrivals are measured at remote terminal locations, not at the main stations used by passengers as destinations. On-time performance (OTP) statistics are grouped in large time intervals (e.g., a.m. rush hour or 24 hr), not the smaller intervals corresponding to a passenger's routine commute. Extra service provided to passengers is not integrated into reported OTP measures, and cancelled service and bypasses are considered delays, even when passengers do not arrive late at their destinations. Schedule adjustments made by dispatchers make trains appear to be on time, even when travel times or platform waiting times are increased. Estimates of average passenger delays are not made or reported by the NYCTA.

The performance model developed by the MTA–IG is designed to measure service as passengers see it, while preserving the capability of producing operational measures. A data base of approximately 50,000 trains, reaching their respective central business district (CBD) stations between 6:00 and 10:00 a.m., was constructed from subway records. The passenger orientation influenced every aspect of model design. To illustrate the methods discussed, 1988 data were analyzed for several subway services (a total of 5,103 trains): the No. 1 southbound (1,147 trains), the F northbound (700 trains), both the No. 4 northbound (926 trains) and southbound (907 trains), and both the No. 5 northbound (546 trains) and southbound (877 trains). All northbound No. 5 trains from Utica Avenue were treated as No. 4 trains, because they are identical services until after the CBD.

It was originally estimated that only half as many trains were needed for the reliable No. 1 line, but on one of the randomly chosen sample days, a derailment caused about half the scheduled service to be cancelled. The elimination of these data could not be justified because the passenger's perspective is inconsistent with the concept of a typical day. Passengers ride the subway on all days, so it is important to preserve the full range of experience. However, the sample size for the No. 1 was doubled to ensure a higher level of accuracy for the statistical estimates. In the final analysis, the derailment caused the annual averages to drop 2 to 4 percent.

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CHOOSING WHERE TO MEASURE

Two of New York's commuter railroads measure morning rush OTP at Penn Station and Grand Central Station, which are terminals as well as the primary destinations for their peak ridership. The situation is not as convenient for the subway system, because most lines have terminals at outlying locations. Though most passengers have deboarded trains at various CBD locations, the NYCTA measures OTP some time later at outlying terminals, where trains have a smaller and altogether different ridership. For example, the NYCTA monitors F trains from Brooklyn at 179th Street in Queens, where they are scheduled to arrive 40 min after departing from the CBD point used in the MTA–IG model. This diagram depicts the F line:

T1——*I*——————*CBD*——————*T2*

T1 represents the originating terminal (Coney Island, Brooklyn), *T2* represents the final terminal (179th Street, Queens), *CBD* represents the midtown CBD point used in the MTA–IG model (West 4th Street), and *I* represents an intermediate point used in the model (Kings Highway).

From an operational point of view, the NYCTA must be concerned with the entire trip of the train, but its method combines two different trips from the passenger's point of view—one heavily loaded inbound trip to the CBD and one much more sparsely loaded outbound trip. Ideally, terminal-to-terminal trips should be measured as two distinct trips, weighted by the number of passengers on each leg of the train's trip. The MTA–IG model does not yet measure service provided for reverse commuters, but accounting for outbound trips remains a necessary future step.

In the morning rush hour, travel times to CBD locations are more relevant to passengers than travel times of trains to remote terminals. However, the travel time from originating terminals to CBD locations (from *T1* to *CBD*) does not represent the travel time of all riders, because many board trains near the CBD. For this reason, it is advisable to choose one or more intermediate control points (such as point *I* in the diagram). In this way, OTP can be calculated for two sets of passengers, those boarding between *T1* and *I* and those boarding between *I* and *CBD*.

Moreover, headways at the intermediate point are preferable to calculating platform waiting times, which are needed for the OTP analysis described later. Headways in the CBD are not as useful for measuring waiting times, because congestion occurring after many passengers have boarded can change the headway distribution significantly.

PASSENGER GROUPS, NOT TRAINS

One important feature of the MTA–IG model allows analysis of the effect of schedule adjustments on passengers, provides for a more appropriate treatment of cancellations and bypasses, and produces realistic information on delays experienced by passengers. This is the concept of passenger groups.

Each scheduled train is seen as representing a group of passengers (or two groups, when using the intermediate station *I* as a control point), and each group must be accounted for separately. When a train is cancelled, the model's computer record does not delete it; rather, it continues to record and calculate statistics for the passengers who would have been on the train. The MTA–IG model imputes a delay figure to those passengers on the basis of the arrival time of the train on which the passengers are estimated to have reached their destination. The decision rule was made that passengers arrived on the next available train. For example, if a cancelled F train's scheduled time at West 4th Street was 8:20, and the next F train arrived at 8:32, a 12-min delay was imputed to the passengers left on the platform because of the cancelled train. In this way, the gaps in service caused by cancellations can be included in calculations of the average delay.

Although passengers in New York cannot always board the next train, no empirical evidence specifies an alternative assumption. Research is now planned to develop this aspect of the model. Until more is known, the next-available-train rule will be used; it is simple, and the direction of error is known. (The severity of the delay is underestimated, especially on the most crowded lines.)

Providing a delay figure for cancelled trains allows a more accurate treatment of bypasses. Occasionally, trains are routed onto an express track to avoid congestion or a disabled train; the NYCTA categorizes bypasses as cancellations, late by definition. A portion of the line's riders were delayed, depending on the number of stops missed. However, passengers on the train may not be so delayed, because bypassing trains often arrive in the CBD on time or ahead of schedule. Moreover, directing the lead train to bypass several stops when a long delay has occurred may help restore service more quickly than having it make all stops at overcrowded platforms; the NYCTA calls this strategy a "battery run."

The MTA–IG model allocates the delay to specific trains based on the severity of the incident. For example, if five stops were bypassed by four trains, the first and last trains might be assigned the delay experienced by passengers who were left at the bypassed stops and the other two would be treated according to their actual travel time (these trains may still be late). This technique treats some of the passengers as late and accounts for the positive results of the bypassing train as well.

VARIATIONS IN OTP STATISTICS

Although a variety of reliability measures are used in the performance model, this section focuses on ways to measure OTP. The following measures of OTP will be discussed:

- Standard OTP,
- Passenger-weighted OTP,
- Operational OTP,
- Total-trip OTP, and
- Weighted total-trip OTP.

Standard OTP

Because New York City subway data are being used and the NYCTA definitions and formulas are known, its method will be used as standard. The TA defines OTP by the following equation:

$$\mathrm{OTP} = \frac{S - L - EC - TC}{S}$$

where

S = total number of trains scheduled,
L = number of trains late by more than 5 minutes,
EC = number of trains cancelled en route, and
TC = number of trains cancelled at the terminal.

Late trains (L) are those that arrive at their destination terminal more than 5 min behind schedule. (The schedule may have been adjusted according to operating procedures designed to even out service in the event of a cancellation or delay). An en route cancellation (EC) may be a train removed from service or simply a train that bypassed one or more scheduled stops. A terminal cancellation (TC) can be caused by shortage of equipment or personnel, or simply a late arrival in one direction that causes a delay in the turnaround trip in the opposite direction. Terminal cancellations are often compensated by dispatching an extra train, but the NYCTA does not include extras in the calculation of OTP.

The MTA–IG methodology makes three significant alterations to this standard method. First, rush-hour OTP is measured at CBD locations instead of destination terminals. Second, smaller time intervals are used—half-hours for the morning rush. The NYCTA's aggregation of all trips from 7:00 to 9:00 a.m. into a single measure does not provide operations managers with sufficient information about when problems occur. If reported publicly, it would not provide passengers with useful information about the service when they ride. Third, OTP is measured for each direction of a line, whereas the NYCTA combines statistics for a single measure of each line. The differences between directions on a line are significant and are more relevant to passengers in this form.

Table 1 presents the OTP of several services calculated with the standard definition, using half-hour intervals. The OTP exhibits a striking degree of variation across the rush hour that is lost by aggregating the results into a single measure for the 7:00 to 9:00 a.m. period. The No.4 north and No.5 both north and south are particularly significant. The difference for the relatively steady F line between the 7:00 to 9:00 a.m. average and the critical 8:30 to 9:00 a.m. period is 8 percent; between the best and worst half-hour periods the difference is 25 percent. For the No.5 south, the difference between the peak half-hour and the 7:00 to 9:00 average is 35 percent; between the best and worst half-hours, the difference is 68 percent.

Table 1 also indicates the variation of OTP for different directions of the same line. The northbound No.4 is on time 36 percent from 9:00 to 9:29 and 64 percent from 9:30 to 9:59; the southbound No.4 is on time 52 percent and 92 percent for the same time periods. The No.5 service differs dramatically by direction for every time period after 7:00.

Passenger-Weighted OTP

A primary goal of a passenger-oriented system is the measurement of the percentage of passengers on time instead of the percentage of trains on time. A simple approach is to weight train OTP on the basis of aggregate passenger counts, to calculate the percentage of passengers who are late or on time. The heaviest weight would go to train trips with the highest ridership at the peak hour. This approach was tested by aggregating the OTP of several lines for the 7:00 to 9:00 a.m. period using the standard method and comparing the result to the measure reached by weighting each half-hour period for each line by passenger count. The two results were nearly identical. Thus, the standard OTP method already includes a form of passenger weight, because the frequency of trains corresponds to ridership volume.

Another form of passenger weight is to divide the trip in two with data at the intermediate station. Are riders at the more remote areas on the line more often late than those boarding closer to the CBD? Passenger counts were used to estimate the ridership for each half-hour interval before and after station *I*. Then the standard OTP was calculated for riders boarding before *I* (actual travel time from *T1* to *CBD* minus the scheduled travel time) and riders boarding after *I* (actual travel time from *I* to *CBD* minus the scheduled travel time) and weighted by the appropriate passenger loads.

When this method was applied to the F line's performance, the results were nearly identical to those of the standard method.

TABLE 1 STANDARD OTP (PERCENT)

Scheduled Arrival at CBD Location (a.m.)	F	No.1	No.4		No.5	
	North	South	North	South	North	South
6:00-6:29	75.9	91.5	90.9	92.4	—[a]	92.4
6:30-6:59	75.0	93.8	90.9	90.1	86.4	85.2
7:00-7:29	77.8	90.8	89.8	85.5	95.4	83.6
7:30-7:59	83.3	89.9	82.1	80.2	87.1	78.0
8:00-8:29	64.8	91.1	86.4	77.9	84.8	60.7
8:30-8:59	64.3	95.3	60.5	50.6	57.3	23.8
9:00-9:29	63.0	90.5	36.3	52.2	39.8	52.2
9:30-9:59	88.6	92.2	63.6	92.0	63.5	87.5
7:00-9:00	72.0	92.0	76.5	72.3	79.9	59.3

NOTE: All northbound No.5 trains from Utica Avenue or New Lots Avenue are grouped with the northbound No.4. Excluding the sample day when a No.1 train derailed would raise the No.1 line's performance 2 to 4 percentage points in individual half-hour periods and 3 points for the 7:00-9:00 period. The CBD point is West 4th Street for the F; Times Square for the No.1; and Grand Central for the No.4 and No.5 in both directions.

[a] No northbound No.5 service before 6:30 a.m.

SOURCE: MTA–IG Analysis of 1988 NYCTA Interval Sheets.

This similarity suggests that delays on the F line occur after the intermediate station (I), at bottlenecks approaching the CBD, and that they affect all passengers.

Operational OTP

Under the definition of operational OTP, to be on time a train must arrive not later than the next scheduled arrival and be no more than 4 min late. This is called operational OTP because the definition of lateness varies with the frequency of service. If short headways are scheduled, then the criterion for on time should reflect whether one train arrives in the slot scheduled for another. This approach was proposed for the NYCTA in legislation introduced in 1989 by New York Assemblywoman Catherine Nolan. Table 2 indicates how operational OTP differs from the standard for two subway services.

The most obvious effects are that operational OTP is usually lower than standard OTP because it uses more stringent criteria, and that this difference grows in the core of the rush hour as headways become tighter. One surprising result is given for the F line from 9:00 to 9:29 a.m. The standard method shows little change from the previous period, but the operational method shows that service has significantly improved. Similarly, the No.4 service is shown to worsen in the 8:00 to 8:29 period, whereas the standard method shows it nearly the same as that of the previous half-hour.

Comparing lines from an operational perspective is different from the rider's view. Riders are interested in the probability of on-time arrival; the No.1 provides much better service than the No. 5. However, in operational terms, lines can be compared only in the context of their infrastructures and service configurations. The performance of two lines can be compared only after controlling for exogenous factors like the number of merges, distance, headways, and equipment reliability. This kind of analysis can only be performed with a sophisticated causal model and a large data base.

Total-Trip OTP

This version of OTP provides the crucial link between travel times and the regularity of service (platform waiting times). A train is late if the actual travel time plus the actual wait exceeds the scheduled travel time plus the scheduled wait by more than 5 min. The actual wait is half the headway—the average wait of all passengers on the train, assuming a uniform arrival rate of passengers onto the platform and no riders left on the platform by the previous train.

TABLE 2 OPERATIONAL OTP OF THE F AND NO.4 LINES

Scheduled Arrival at CBD Location (a.m.)	Standard OTP (%)		Operational OTP (%)	
	F North[a]	No.4 South[b]	F North[a]	No.4 South[b]
6:00-6:29	75.9	92.4	70.4	89.4
6:30-6:59	75.0	90.1	72.2	87.9
7:00-7:29	77.8	85.5	73.3	80.9
7:30-7:59	83.3	80.2	75.0	74.1
8:00-8:29	64.8	77.9	53.7	70.8
8:30-8:59	64.3	50.6	50.8	41.6
9:00-9:29	63.0	52.2	61.1	42.5
9:30-9:59	88.6	92.0	81.4	89.8

[a] F northbound serves Brooklyn and the Lower East Side of Manhattan.
[b] No. 4 southbound serves Upper Manhattan and the Bronx.
SOURCE: MTA–IG Analysis of 1988 NYCTA Interval Sheets.

The method of combining travel times and waiting times permits analytical treatment of useful schedule adjustments. An en route schedule adjustment may be required when dispatchers learn that a train must be cancelled. The train preceding the cancelled train is held at a station to close the gap behind it. This process delays the travel time of the passengers on the train, but spares many passengers down the line a longer waiting time. In effect, a schedule adjustment spreads out the delay over two or more trains. Schedule adjustments made at terminals may not affect travel times, but they cause some passengers to be late because of increased waiting times. By separately calculating the actual travel and the actual waiting times, the model accounts for the increased lateness for some passengers as well as the decreased wait for others because of the schedule adjustments.

Under the definition of total-trip OTP, passengers are late if

$$(ATR + AW) - (STR + SW) > 5 \text{ min}$$

where

ATR = actual travel time,
AW = average actual wait, or one-half the actual headway,
STR = scheduled travel time, and
SW = average scheduled wait, or one-half the scheduled headway.

Each cancelled train represents a passenger group for which travel and waiting times are calculated separately. The passengers who would have boarded the cancelled train are attributed the travel time of the next available train. Some cancelled trains are not late under this definition. If the next available train reached the key point 5 min or less from the scheduled time of the cancelled train, then it makes no sense in this model to record this passenger group as late.

The incorporation of waiting times into the calculation of OTP allows the model to account for extra trains sent out to fill a gap in service. The extra trains will reduce the waiting time of passengers, improving OTP under the total-trip method.

The results of this analysis are presented in Table 3. In general, the standard and total-trip methods yield similar results. The apparently larger differences in the shoulder of the rush are probably caused by larger headways.

However, passengers cannot be assumed to be distributed equally among trains. When service is not timely, it tends to be more erratic. Headways become uneven, and trains are often bunched together. The waiting time for a bunched train can be as short as 1 min. If that train's travel time was 7 min more than scheduled but the waiting time was 2 min less than scheduled, it would be counted as on time (only 5 min late) by the total-trip method. The reduced waiting time offsets the longer travel time. This effect seems to be the reason the total-trip method gives results similar to the standard method. However, bunched trains do not represent better service.

TABLE 3 STANDARD OTP VERSUS TOTAL-TRIP OTP FOR THE F AND NO.4 LINES NORTHBOUND

Scheduled Arrival at CBD Location (a.m.)	Standard OTP (%)		Total Trip OTP (%)	
	F	No.4	F	No.4
6:00-6:29	75.9	90.9	63.2	88.5
6:30-6:59	75.0	90.9	75.0	86.4
7:00-7:29	77.8	89.8	76.4	86.4
7:30-7:59	83.3	82.1	81.5	80.4
8:00-8:29	64.8	86.4	66.7	81.8
8:30-8:59	64.3	60.5	66.7	62.0
9:00-9:29	63.0	36.3	65.7	42.1
9:30-9:59	88.6	63.6	82.9	72.2

NOTE: The F and No.4 northbound lines serve Brooklyn.
SOURCE: MTA–IG Analysis of 1988 NYCTA Interval Sheets

Therefore, a method must be devised to account for the effects of irregular service on passenger OTP. One way to account for this effect is to weight individual trains by the number of passengers estimated to be on a train; such an approach is outlined in the following section.

Weighted Total-Trip OTP

Assuming a uniform rate for passenger entries into the station, a longer wait will cause passengers to accumulate on station platforms. As a result, a train that comes after a delay will be more crowded than the trains following. Trains with longer headways will be more crowded than trains bunched behind. For example, if 20 passengers arrive every minute, a train with a headway of 8 min will pick up 160 passengers; a train following with a headway of 2 min will pick up only 40 passengers. The headway of the first train is four times longer than the headway of the second; similarly, the number of passengers is four times as great.

Therefore, headways provide a simple method for weighting individual trains by their passenger loads. As long as the subject is a single route within a narrow time frame, the actual rate of passenger arrival is not needed: the ratio of headways will always give the ratio of passengers. Instead of calculating OTP by the standard formula

$$\text{OTP} = \frac{\text{number of trains on time}}{\text{total number of trains}}$$

the following is used:

$$\text{OTP} = \frac{\text{total headway of on-time trains}}{\text{total headway of all trains (late and on time)}}$$

This is the same as

$$\text{OTP} = \frac{\text{total number of passengers on time}}{\text{total number of passengers (late and on time)}}$$

An example may be helpful. If two trains are late and two are on time, the standard OTP would be 50 percent. However, if the on-time trains were bunched behind the late trains so that the headways of the on-time trains are 2 and 3 min but the headways of the late trains are 6 and 4 min, then the weighted method would give on-time performance as $(2 + 3)/(2 + 3 + 6 + 4) = 33$ percent. More passengers were on the delayed trains.

If the weighted total trip method is used to estimate OTP for the northbound No.4, the results are consistently lower than those from the simple total-trip method. They are sometimes higher and sometimes lower than those of the standard method. Between 6:30 and 7:00 a.m., the standard OTP is 90.9 percent, the total-trip OTP is 86.4 percent, and the weighted total-trip OTP is 82.2 percent. The weighted method's estimate is almost 10 percent lower than that of the standard OTP. However, between 9:00 and 9:30 a.m., the standard OTP is 36.3 percent, whereas the weighted total-trip OTP is 39.9 percent (about 10 percent higher).

The major impact of irregular service on OTP is the creation of overcrowded conditions such that passengers cannot board the next available train. When this situation occurs, the waiting times and the number of late trains are larger than either the total-trip or weighted total-trip method estimates, and OTP consequently is lower. To deal with this issue, an empirical study must be made of the relationships between the distribution of headways, the distribution of passengers, and operating capacity.

AVERAGE DELAY

Reliable figures on delays are rarely presented publicly, and when they are, they focus on the delay of trains, not passengers. Because cancelled trains never reach the destination terminal, no lateness figure is assigned to them, and they are dropped from the analysis. This method is used by the Long Island Rail Road and Metro-North, the two commuter railroads within the MTA. The NYCTA does not report the average delay for its lines or for the subway system.

The average delay of passengers is a critical variable both for purposes of evaluation of service by oversight or consumer groups and for management in appraising operational strategies to minimize inconvenience to passengers. Table 4 presents the results for two routes. The average delay can be as much as 27 percent higher with cancellations included (F line, 6:30 to 6:59). A graph of the delay distributions could be expected to look very different.

Both routes tend to have larger average delays when delays due to cancellations are included, but this result is not always

TABLE 4 AVERAGE DELAY PER LATE TRAIN

Scheduled Arrival at CBD Location (a.m.)	Ignoring Cancellations (min)		Imputing Time to Cancellations (min)	
	F North[a]	No.4 South[b]	F North	No.4 South
6:00-6:29	10.8	11.0	11.1	12.0
6:30-6:59	7.8	10.3	9.9	10.3
7:00-7:29	7.4	9.3	9.0	9.2
7:30-7:59	8.7	9.1	9.4	10.4
8:00-8:29	9.2	9.6	9.7	11.1
8:30-8:59	8.0	9.2	9.2	11.0
9:00-9:29	9.6	9.8	10.6	10.8
9:30-9:59	7.7	6.3	8.3	6.3

[a] F northbound serves Brooklyn and the Lower East side of Manhattan.
[b] No.4 southbound serves Upper Manhattan and the Bronx.
SOURCE: MTA–IG Analysis of 1988 NYCTA Interval Sheets

the case. The average delay decreased for the No.4 southbound (7:00 to 7:29), because abandoned trains resulted in delays less than the average. Of course, the average delay figures could change even more if weighted by passengers and corrected for overcrowding.

CONCLUSIONS AND DIRECTIONS

The MTA–IG model's passenger orientation is expressed in fundamental aspects of the analytical framework, such as the choice of measurement points; the definition of a trip; the use of time periods; the treatment of cancellations, bypasses, and extra service; the inclusion of waiting times; and the search for a method of weighting measures by passenger loads. The major area for further development involves research to account for the effects that overcrowding and irregular headways have on passengers.

The analytical objective of measuring the passenger's experience initiated a search for ways to weight the train data, to translate the probabilities for trains' being on time into the probabilities that passengers were on time. A weighting procedure using aggregate passenger volume and aggregate OTP data was found to be inadequate for measuring the probability of on-time arrivals for passengers. Such a statistic will add little information to the standard method, which already accounts in part for differences in passenger volume by graduations in service frequency. For perfectly regular service with no overcrowding, a weighting system would be unnecessary. However, overcrowding and irregular headways, with a resulting uneven passenger distribution, make the development of a weighting method necessary. A weighted total-trip method was developed to address uneven passenger loads. This method is a good first step, but it needs empirical verification before application.

The relationship between headway variance and passenger load distribution should be studied to determine how crowded a train will be, given its own headway and the headway of trains preceding it. This task and exploring the issue of passenger loads under constraints of operating capacity (i.e., the problem of the first or subsequent trains being too crowded for some riders to board) represent the main directions for further study.

The actual passenger arrival rates on a given day cannot be known. Assumptions must be made on the basis of the most recent traffic-checking data. A passenger-oriented model, therefore, requires an adequate traffic-checking program. For the most comprehensive system, precise, up-to-date estimates are needed for every line in every time period. However, considerable analytical power can be realized with knowledge of relative passenger volumes (i.e., knowing the ratios of passengers from one time period to another and line-to-line ratios). This approach is adequate for most purposes and does not require such an intensive traffic checking effort. Ridership growth on the system may not change the distribution in relative terms.

The model's passenger orientation does not preclude measuring service in operational terms. Indeed, the data base and analytical framework needed to support the model permit impressive flexibility in analyzing service. A number of different methods of calculating OTP were examined in this paper. No single method is recommended for operating agencies. Some methods are more suited to particular diagnostic operational uses, but certainly the passenger orientation is critical for questions of operational effectiveness, especially in the context of a strategic management approach.

One of the most valuable aspects of the sample-based, analytical approach used to support the MTA–IG model is its flexibility. Operating agencies usually collect performance data according to written standard procedures. For example, NYCTA field personnel phone in how many trains were late or cancelled within a certain time period, a simple and efficient (though often inaccurate) procedure that, unfortunately, predetermines the scope of analysis. The statistical data base used here permits a wide range of analyses using different definitions of OTP, different time periods, and combinations of merging services. The analytical applications go beyond OTP; headways, waiting times, travel times, cancellations, delay recovery, schedule adequacy, and other statistics can all be measured. The MTA–IG is also preparing reports on service regularity and passenger waiting times and developing the data base as a comprehensive causal model.

The performance measurement system described here is more complicated to construct at present than the standard procedures used by most operating agencies. Even though it is based on a sample, considerable effort is required to build the data base and maintain its accuracy. The production of results requires a certain time lag, while operating agencies often need timely feedback. Why should a transit agency invest time and money in such a system?

Operating agencies stand to benefit the most from such an analytical system. Because reliable passenger service is their primary mission, at least in theory, measuring the passenger's experience should be an important goal.

Expressing performance in these terms also more accurately quantifies the expected benefits and their link to specific capital investments. Proposed performance benefits to riders can be instrumental in persuading UMTA and oversight agencies of the importance of proposed projects. A measurement system that overestimates performance by discounting the effect of irregular service on passengers or levels out the variation in performance by too much aggregation is also likely to underestimate the benefits to passengers of new policies or capital improvements. Operating agencies can also benefit from more sophisticated and flexible analytical methods for operations analysis, scheduling, and planning.

The potential users of such a system are not limited to operating agencies. In the contemporary institutional landscape, a number of federal, state, and local agencies, like the MTA–IG, have oversight responsibilities for monitoring program expenditures and program outcomes. Also, citizen activist organizations independently monitor service. For these organizations, the essential requirements are accuracy and an evaluation expressed in terms of the service experienced by passengers. It would be sufficiently timely to produce statistical results for a given year early in the following year. The MTA–IG's experience suggests that this procedure is entirely feasible after an initial period of organizational development and research.

The most problematic issue for operating agencies is to meet their needs for reporting on performance within 24 hr. This responsibility can be accomplished for the proposed system only through technological developments—the selective use of accurate automated vehicle monitoring systems and computer-supported dispatching at terminals and selected intermediate stations. These long-term goals require capital investment and employee development. A transit agency planning to introduce these technologies should consider the analytical capabilities they provide to improve the agency's understanding of service delivery problems and to evaluate managerial strategies.

DISCUSSION

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The authors correctly state that the definition of reliability in transit system evaluation requires additional attention. The purpose of this discussion is to contribute some suggestions toward further development of the concept of transit service reliability.

Evaluation of transit service quality with respect to a performance characteristic can be classified into two different dimensions. First, that performance characteristic has to be defined and measured by itself; second, it can be weighted by its impact on passengers. The latter aspect involves volumes and characteristics of passengers affected by the service performance.

The authors point out the problem of finding the appropriate location for measuring reliability, which is defined as the percentage of trains arriving within 0 to 4 min from the scheduled time. They correctly suggest that the on-time performance should be measured at the point where most passenger trips terminate, rather than at the end of the line, which may be in the suburbs where passenger volume is extremely low. In addition, reporting should be done for shorter intervals (i.e., 30 min rather than 1 hr).

The importance of reliability depends partly on service headway. With short headways, delays that approach the headway in length are not felt very much because passengers, except the ones on the delayed vehicle, may not notice that difference. The vehicle they take may not be the scheduled one, but it serves them close to schedule. Under such conditions, maintaining regularity of service (uniform headways) becomes more important than maintaining schedules. On lines with long headways, however, reliability is of utmost importance; passengers rely on that service and often have no alternative.

Passengers sometimes perceive the impact of a delay according to the duration of their trip. A 10-min delay on a 20-min trip may be more irritating than the same delay on a 60-min trip. Yet, reliability of service is equally important for all trip lengths, because the passenger is equally concerned with arriving on time regardless of the distance traveled.

On the passenger side, passenger volume expresses the breadth of the impact of service reliability, as the authors correctly point out, whereas the type of impact can be measured by the sensitivity of passengers to reliability (or lack of it). Sensitivity is a function of the consequences of low reliability. If the consequences are serious, passengers are very irritated by any delays. An extreme example is travel to the airport, where delays on transit lines may cause the passenger to miss a flight. The passenger traveling for leisure or casual shopping is much less sensitive to a similar delay.

Passenger characteristics that influence this sensitivity include such factors as trip purpose, trip duration, and ridership composition. Trip purposes could be classified and greater weight be given to work, business, and school trips than to social and shopping trips. The second characteristic, ridership composition, can be included through grouping by age; for senior citizens, on the average, travel reliability is less important than for persons in working and school ages.

The importance, complexity, and multiple interrelationships of the influencing factors suggest that the reliability of each line should be measured by models that include the most relevant of these factors. However, this can be impractical because of extreme complexity of the required data collection and analyses.

The model can be simplified by use of fewer factors that could act as proxies for all the discussed elements. Further research should be done to derive these elements.

For example, it would be impractical to try to measure the percentages of passengers by trip purposes, passenger age, and other characteristics in measuring impacts of reliability. However, it may be practical to distinguish reliability during peak hours, dominated by work and school travel, from reliability of service during offpeak hours, used more by discretionary travelers.

It is interesting that the authors' much more sophisticated method for computing reliability has not resulted in very different findings from those obtained through conventional reliability measures. That may indicate that the conventional methods are robust enough to produce reasonable results. Yet, the increasing need for more sophisticated analyses of reliability requires further efforts to develop more complex and sensitive, yet practical, methods.

The authors of this discussion are solely responsible for its contents and conclusions, which may not represent the official view or policies of SEPTA.

AUTHORS' CLOSURE

The discussants have provided interesting extensions of the conceptual approach presented in the paper. The issue of the passenger's sensitivity to poor reliability opens another fruitful area for analysis. Although the paper's use of demographic characteristics is limited to passenger distributions and volumes, the concept of passenger sensitivity brings into the analysis the realization that passengers in different circumstances will respond differently to delays. This line of thought also suggests that the relationship between the passenger's tolerance of delays and the magnitude of the delay may not be linear. Passengers may be inconvenienced but tolerant of small delays, but increasingly dissatisfied at higher levels. An OTP measure that acknowledges such subjective factors might require giving greater weight to larger delays.

The discussants identify three factors that influence this sensitivity, or tolerance of delay—trip purpose, trip duration, and ridership composition. The authors suggest that trip purpose could be included by giving greater weight "to work, business, and school trips than to social and shopping trips." The analytical problems are to find a good proxy for these different purposes and to decide how much to weight them. A possible solution might be to use a different standard (i.e., how many minutes is late?) for reliability for midday and offpeak than for rush hours, factoring in estimates of ridership composition. The variation in standards could be derived from a survey of passengers at different times.

In considering trip duration, many passengers use linked trips. Conventional measures focus on single lines, but transfers introduce a new element. Using linked trips can even lead to a more adequate appraisal of service experienced by passengers using buses as feeders to the subway.

The discussants also note the robustness of the measures produced by conventional methods. Our efforts to combine waiting times with travel time—the total-trip method—had little effect on our estimates of reliability in the core of the rush hour. Larger differences were produced for the shoulders of the rush. In subsequent analysis, we found up to 14 percent differences for given time periods on certain lines. This variation suggests that the total-trip method is most useful when headways are larger, especially during midday and evenings. The differences between the total-trip and conventional methods are greater still when a weighting method is used, as discussed in the paper.

For measuring reliability in the core of the rush hour, our more sophisticated methods currently yield results not much different from the conventional method. However, in the core of the rush, overcrowding causes passengers lateness that cannot be detected by merely timing the trains. Considerable numbers of passengers cannot board the first train that passes because of overcrowding. Therefore, we believe it is necessary to increase the sophistication of our method rather than rely on the conventional approach, because the latter fails to account for the full extent of delays experienced by passengers.

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Evaluating a Large Number of Station and Alignment Alternatives

SALLYE E. PERRIN AND GREGORY P. BENZ

A novel three-step evaluation process was used to select the final alignment, station locations, and construction method for the Maryland Mass Transit Administration's rail transit extension into northeast Baltimore. During preliminary engineering of this subway line, known as Section C, several station box locations for two stations, numerous route alignments, and two tunnel construction techniques resulted in 24 alternative designs for the extension. Over a dozen evaluation categories, many with multiple criteria, had to be addressed including cost, patron access, constructability, environmental and community impacts, and joint development potential. A conventional evaluation matrix was not a practical nor appropriate means to select the best option. The evaluation procedure used had three steps—the first of which was a construction methodology evaluation conducted within a capital cost threshold established by a financing cap. Then, individual components that made up the alternatives, such as a station location, were evaluated to determine the best-to-worst ranking against the relevant criteria. The alternatives that included the most top-ranked components were then evaluated using a focused display matrix that included only those criteria that distinguished the remaining alternatives. This procedure, which was successful in identifying the plan for the extension now under construction, provides a practical means enabling engineers, architects, planners, operators, and policy makers to manage a large number of alternatives and evaluation criteria.

When the number of alternatives and evaluation criteria exceeded the practicability of a conventional evaluation matrix, an innovative three-step evaluation procedure was developed and successfully applied. The procedure demonstrates that a complex set of alternatives can be evaluated by disaggregating the alternatives into components and focusing on the distinguishing features among the alternatives rather than the absolute measures. The procedure reduces the number of alternatives and criteria to a manageable number that can be handled by more conventional evaluation techniques.

Section C of the Baltimore Metro will extend service from downtown at Charles Center into the northeast section of the city to the Johns Hopkins Hospital medical center. The extension will be about 1.5 mi in length and will include two stations—one called Shot Tower/Market Place on the eastern side of Baltimore's central business district, and one at Johns Hopkins Hospital, a major employment center. All the facilities for the extension to Johns Hopkins Hospital are underground, through an area that was part of the early settlement area of Baltimore. Subsurface features include water-saturated soils, areas where the harbor was filled, old and modern utilities (including a conduit built in 1910 that carries the Jones Falls stream), and potential archaeological features. The extension, consisting of twin circular tunnel trackways driven partially with compressed air, is now in construction. The stations will both be built by cut-and-cover methods, i.e., open excavation from the surface.

At the end of the UMTA Alternatives Analysis/Draft Environmental Impact Statement (AA/DEIS) process for the rail transit project, the alternative extending from the present metro terminus at the Charles Center Station under Baltimore Street, continuing eastward below Fayette Street, and subsequently northward under Broadway to a new terminus at Johns Hopkins Hospital, was selected as the preferred alternative (see Figure 1). Several variations of the preferred alternative merited further investigation during the preliminary engineering/final environmental impact statement (PE/FEIS) phase of the project. Design options that were to be evaluated and refined during PE/FEIS included alignments below either Baltimore Street or Fayette Street; shallow or deep profiles; cut-and-cover construction instead of shield-driven, soft-ground, and rock tunneling; variations in the location of stations and station entrances; rail-bus transfer facilities; and other possible changes in the then-defined characteristics of the preferred alternative.

The initial phase of the PE/FEIS consisted of an evaluation of alternatives leading to a recommendation for the design alternative to be chosen for advancement into preliminary design. The process was used to evaluate alternative alignment and station options and construction methodologies.

BASIC BUILDING BLOCKS

The set of alternatives for the Metro Extension resulted from the combination of various station locations, crossovers, alignments, and different methods of construction. A total of 24 possible alternatives were defined. A traditional evaluation process that would compare this set of 24 alternatives was determined to be too cumbersome, and, more important, individual differentiating factors relative to station locations and construction methodology tended to be overshadowed by alignment issues.

Because the alternatives were defined by stations and crossover locations, alignments, and construction methods, a basic building block approach was applied for comparing the components. The individual components that make up each alternative were assessed individually to arrive at the preferred option. The components were termed

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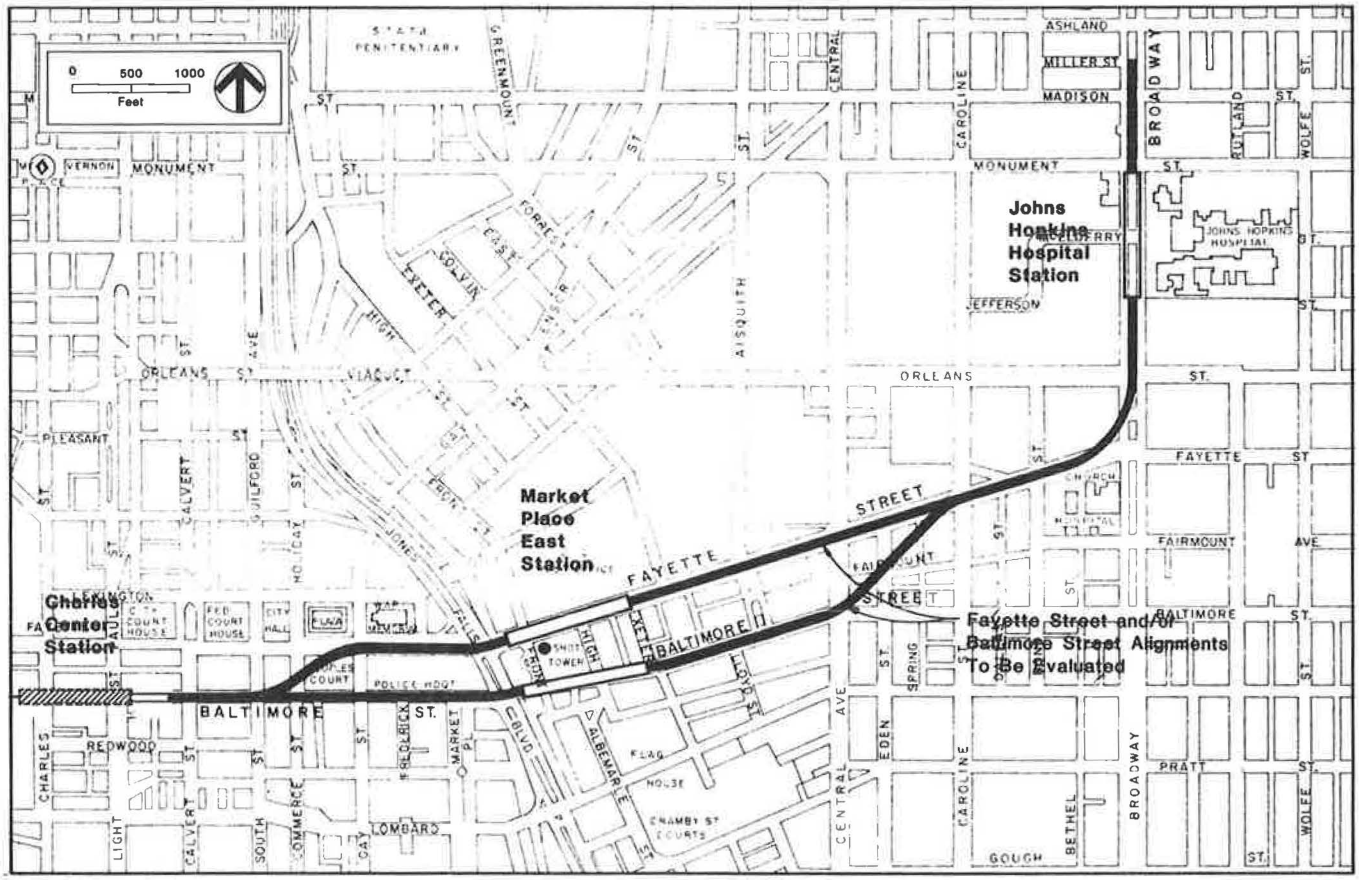

FIGURE 1 Preferred alignment—AA/DEIS.

- *Conditions.* Refers to station locations and related crossover variations. There are nine conditions, five at Shot Tower/Market Place and four at Johns Hopkins Hospital. Some station locations, especially at Shot Tower/Market Place, are only possible with certain alignment options.
- *Alignments.* There are four alignment variations, one on Fayette Street, one on Baltimore Street, and two alternatives that transition from Baltimore Street to Fayette Street at different locations.
- *Construction Methodology.* Refers to the mix and extent of cut-and-cover construction and tunneling.

The nine station conditions are as follows:

- *Shot Tower/Market Place*
  - —Condition 1: West of the Jones Falls Boulevard under Baltimore Street.
  - —Condition 2: Straddling the Jones Falls Boulevard under Baltimore Street.
  - —Condition 3: East of the Jones Falls Boulevard under Baltimore Street.
  - —Condition 4: East of the Jones Falls Boulevard under private property, diagonally between Baltimore and Fayette Streets.
  - —Condition 5: Underground station east of the Jones Falls Boulevard, in Fayette Street.
- *Johns Hopkins Hospital Station* (all under Broadway with tailtrack immediately north of platform)
  - —Condition 6: North oriented with direct connection to the north bus transfer facility. No. 10 crossover immediately south of platform.
  - —Condition 7: More southerly oriented than Condition 6, indirect connection to north bus transfer facility. No. 15 crossover located on Fayette Street west of curve.
  - —Condition 8: Same platform location as Condition 7, with direct connection to north bus transfer facility and hospital development. No crossover immediately south of platform.
  - —Condition 9: Most southerly oriented station location, with direct connection to south bus transfer facility and hospital development. No. 10 crossover immediately south of platform.

The four alignment variations all start under Baltimore Street at the existing Charles Center Station. They are summarized below:

- *Alignment I.* A Fayette Street alignment that transitions from Baltimore Street to Fayette Street near Gay Street, and then curves over to Broadway, north of Orleans Street. A refined version of the Fayette Street alignment shown in the AA/DEIS.

- *Alignment II.* A Baltimore Street and Fayette Street alignment that transitions to Fayette Street at about Eden Street, and then curves over to Broadway, north of Orleans Street (same as Alignment I). This alignment is a refined version of the Baltimore Street alignment shown in the AA/DEIS.
- *Alignment III.* A Baltimore Street alignment, continues under Baltimore Street all the way to a block east of Caroline Street where it curves over to Broadway at a point just south of Fayette Street. (Does not follow Fayette Street at all.)
- *Alignment IV.* A variation of Alignment II that stays under Baltimore Street only as far as the Jones Falls Boulevard where it curves up to Fayette Street, and then curves over to Broadway north of Orleans Street (same in this section as in Alignments I and II).

The combination of variations in conditions, alignments, and construction methodologies resulted in 24 alternatives that were evaluated by this process. These alternatives, perhaps better designated as "design options," are really design variations of the recommended scheme that are out of the AA/DEIS process. However, for the purpose of this evaluation the 24 design options are designated as shown in the matrix of Figure 2.

OUTLINE OF THE PROCESS

The evaluation was conducted in three steps. In the first step, comparative costs for each alternative were reviewed to determine if a significant cost saving could be realized by cut-and-cover construction versus tunneling for the alignments. The evaluation was performed within the context of a capital financing cap established by the amount of funds available from an Interstate transfer.

In the second step, the components that make up the alternatives (conditions and alignments) were assessed against measures that reflect the key factors and issues at each station area and along the alignment. The information was presented in a simple matrix with a relative rating given to the condition or alignment for each evaluation measure. The measures fell under seven major headings that best distinguished significant differences among the station conditions and alignments. To summarize the evaluation, an overall preferred

Alignment	Alternative	Station Condition		Line Structure Construction Features						
				West of Jones Falls Blvd		East of Jones Falls Blvd			Curve in Broad	
	Description	Market Place	Johns Hopkins	Tunnel	Cut & Cover	Tunnel	Cut & Cover	#15 Crossover	Tunnel	Cut & Cover
Fayette (Alignment I)	I.	5	6	■		■			■	
	I.A.	5	7	■		■		■	■	
	I.A.1.	5	7	■			■	■		■
	I.A.2.	5	7	■			■	■	■	
Baltimore (Alignment II)	II.	1	6	■		■			■	
	II.A.	2	6	■		■			■	
	II.B.	3	6	■		■			■	
	II.C.	1	7	■		■		■	■	
	II.C.1.	1	7		■		■	■		■
	II.D.	2	7	■		■		■	■	
	II.D.1	2	7		■		■	■		■
	II.E.	3	7	■		■		■	■	
Baltimore/Broadway (Alignment III)	III.	1	8	■		■			■	
	III.A.	2	8	■		■			■	
	III.A.1.	2	8	■			■		■	
	III.B.	3	8	■		■			■	
	III.C.	1	9	■		■			■	
	III.D.	2	9	■		■			■	
	III.E.	3	9	■		■			■	
Baltimore/Fayette (Alignment IV)	IV.	1	6	■		■			■	
	IV.A.	4	6	■		■			■	
	IV.B.	1	7	■		■		■	■	
	IV.C.	4	7	■		■		■	■	
	IV.C.1.	4	7	■			■	■		■

FIGURE 2 Alternatives description matrix.

assessment rating was given to those conditions and alignments that were clearly better. Once this step was completed, the over-all assessment was carried over to Step 3 (Alternatives Assessment).

In the third step, the preferred conditions and alignments were entered into a second matrix that listed all of the remaining alternatives. Because each alternative comprised various station conditions and alignments, this step involved identifying the alternatives that included the greatest number of preferred conditions and alignments. By this process, the alternatives that did not include preferred conditions or alignments were quickly eliminated and an overall preferred alternative (or alternatives) was identified. If a clear choice did not emerge from the second matrix, further evaluations could proceed with the most promising alternatives identified at that point.

Step 1: Comparative Costs for Construction Methods

As part of the process leading to an evaluation of each of the defined alternatives, the need for comparative cost estimates was determined. It was anticipated that there might be significant differences in construction and right-of-way costs between the set of alternatives that involved driven tunnels and those that employed cut-and-cover construction for the line sections, and that these differences might offset other advantages and disadvantages that could be attributed to an alternate. For the purpose of this examination, the cost estimating would only involve those elements that were unique to each alternative, and those elements that were common to all would be excluded at this time. It was also established at this time that the total project had a $300 million (1986 dollars) funding cap and any alternative that exceeded that amount would be viewed as fatally flawed and eliminated from further evaluation.

The basic elements for each alternative estimate were the station structures and the specific line structure configuration for that alternative, which were developed around the horizontal and vertical alignments for each, and construction by a method determined by the site-specific geotechnical requirements at each location. It was assumed that all station structures would be constructed from the top down with cut-and-cover construction. The cost estimate for stations would include all structural elements and contractor's costs to build the station shell but would not include station finish or mechanical and electrical costs that would be essentially similar for all stations.

Both for driven tunnels and cut-and-cover construction, including applicable stations, provisions for underpinning or protection of existing buildings and structures were factored into the cost estimates on a site-specific basis for each alternative. Because all alternatives require passing under the Jones Falls conduit with differing construction methodologies (i.e., by driven tunnel, cut-and-cover, or cut-and-cover with a straddle station), cost estimates for each method were incorporated into the appropriate alternative.

As with station structures, these estimates only considered the structural elements for line structures and contractor's costs and did not include trackwork, traction power, train control and communications, and ventilation costs, which would be similar for all alternatives. In addition to the comparative construction costs for each alternative, preliminary right-of-way costs were developed for each alternative. The right-of-way cost estimate for each alternative, combined with the construction cost estimates, provides a total comparative cost estimate for each alternative.

The cost estimates are shown in Figure 3. An immediate and important conclusion was drawn from these estimates. Several alternatives were developed to specifically provide for cut-and-cover construction of line structures as an alternate for driven tunnels on the basis that such a construction technique might be materially less costly (although with significant surface disruptions and community impacts) and should therefore be given consideration. Taking into account the necessary factors relating to the costs for cut-and-cover construction for the specific alignments developed, the comparative construction costs clearly indicated that cut-and-cover construction was not less costly, but in fact was significantly more costly than the driven tunnel comparison alternative.

Because the reason for including such cut-and-cover alternatives was not borne out by the cost estimates, there was no justification for continuing to include those six alternatives in the ensuing evaluation of alternatives. Accordingly, that set was dropped from the list of potential alternatives for continued consideration.

Step 2: Component Assessment

Evaluation Measures—Alignments and Conditions

In Step 2 of the evaluation process, evaluation measures were reviewed and screened to include those key issues or factors that could be used to distinguish the significant differences among the various station conditions and alignments. Thus, issues that were more or less the same across all of the components were not included.

The measures fell into the following seven major headings:

- Constructability and cost
- Patronage and service
- Traffic impacts during construction
- Displacement and relocation
- Environmental impacts
- Community or agency concerns
- Private sector participation

Many of these headings included several distinct issues or factors, and those were treated separately. In the following paragraphs, each of the evaluation measures is discussed with the critical factors affecting the evaluation highlighted. In some cases, the measures were applicable only to the station conditions and not to the alignments.

Constructability and Cost

The constructability feature addressed the degree to which a construction project for either a station or alignment (tunnel) could be anticipated to proceed smoothly, on schedule and with little potential for additional costs due to delay, extensive

Alignment	Alternative Description	Station Condition		1986 Comparative Costs*		
		Market Place	Johns Hopkins	Construction	R.O.W.	Total
Fayette (Alignment I)	I.	5	6	97,918	1,950	99,868
	I.A.	5	7	98,934	1,950	100,884
	I.A.1.	5	7	113,942	3,460	117,402
	I.A.2.	5	7	104,695	1,950	106,645
Baltimore (Alignment II)	II.	1	6	97,517	1,170	98,687
	II.A.	2	6	97,856	1,170	99,026
	II.B.	3	6	100,290	1,170	101,460
	II.C.	1	7	98,064	1,170	99,234
	II.C.1.	1	7	125,819	4,300	130,119
	II.D.	2	7	98,406	1,170	99,576
	II.D.1	2	7	123,945	4,300	128,245
	II.E.	3	7	101,024	1,170	102,194
Baltimore/Broadway (Alignment III)	III.	1	8	101,724	1,010	102,734
	III.A.	2	8	101,566	1,010	102,576
	III.A.1.	2	8	118,025	1,010	119,035
	III.B.	3	8	105,595	1,010	106,605
	III.C.	1	9	99,206	855	100,061
	III.D.	2	9	98,367	855	99,222
	III.E.	3	9	102,394	855	103,249
Baltimore/Fayette (Alignment IV)	IV.	1	6	95,958	1,220	97,178
	IV.A.	4	6	96,849	2,770	99,619
	IV.B.	1	7	95,039	1,220	96,259
	IV.C.	4	7	98,213	2,770	100,983
	IV.C.1.	4	7	105,376	4,250	109,626

FIGURE 3 Comparative cost estimates.

change orders due to unforeseen field conditions, or contractor's claims. In effect, constructability was considered as a measure of risk inherent in the construction of any given alternative.

Although constructability would ultimately be reflected in cost, it would not be quantifiable at this point in the process and, therefore, needed to be considered as one of the measures for evaluating differences between alternatives. The cost measure was based on the comparative cost estimates for each alternative, as described previously. Engineering factors are reflected in the comparative cost estimates and were consequently addressed in this evaluation measure. The major variations in cost were attributable to the costs associated with station conditions rather than alignments, so the station cost issues dominated the assessments. Station depth, volume, maintenance of traffic (due to use of cut-and-cover construction for stations) and geotechnical concerns were major influences on station costs.

Patronage and Service Aspects

This category included issues concerned with the relative attractiveness, convenience, and safety for the users of the Metro extension, and the operations of the bus and rail transit services as follows:

Patronage. This measure reflected the attractiveness of a station condition to serve generators or attractors of transit trips. The travel demand model is relatively insensitive to minor variations caused by differing entrance locations in the same general area. A more judgmental approach was utilized in this analysis to supplement the travel model data.

Patron Convenience and Safety. This measure related to how well a station condition would serve the ridership in the surrounding market area. Real or perceived safety concerns were included as well to specifically assess patron crossing of the Jones Falls Boulevard at Shot Tower/Market Place, either at grade or by a pedestrian tunnel connected to the station.

Bus Passenger Interface. This measure addressed the relative convenience for those transit users who would transfer at Johns Hopkins Hospital Station between feeder bus and rail transit services.

Bus Operations. This subheading addressed the bus routing and operating cost impacts of the various off-street bus transfer facility locations associated with the Johns Hopkins Hospital Station.

Rail Operations. The measure addressed the impacts of a condition or alignment on rail service operations and costs including handling of emergency situations. The location of the crossover at Hopkins is the focus here. It also includes station-related operations.

Traffic Impacts During Construction

This measure addressed the degree to which the construction of an alignment section or station affected traffic flow. The elimination of cut-and-cover construction for line sections reduced the impact of construction on traffic; however, construction access shafts and the delivery and removal of materials associated with tunneling could affect traffic flow. The stations and associated facilities would all be constructed using the cut-and-cover construction technique.

Displacement and Relocation

This measure is based on the number and character of the residences and businesses that would be displaced and would have to be relocated.

Environmental Impacts

This category focused on two areas that are of specific concern along the corridor: impacts on parklands and historic properties and noise and vibration impacts from both construction and operations. Other environmental concerns were considered in the development of the alternatives; however, none of the impacts was found to be significantly different among the various conditions or alignments. The two areas of specific concern are

Parkland and Historic Areas. This category related to the short-term disruption or the long-term impacts of the station or alignment on the several open-space or historic structures and areas in the corridor.

Noise and Vibration. This issue addressed construction or operational noise and vibration associated with a station or alignment. It was a particularly critical concern in the vicinity of Church Home Hospital and Johns Hopkins Hospital as well as near historic structures and where the alignment passed beneath structures.

Community or Agency Concerns

This measure reflected the positions and attitudes of the various public agencies, community groups, and residents expressed at meetings and public hearings during the AA/DEIS phase of the project development, or in subsequent meetings. The opinions were concerned primarily with the location of station entrances and location of the cut-and-cover construction.

Private Sector Participation

This heading addressed the degree to which a station condition provided the opportunity for joint development at the station or for possible private sector contributions to the capital or operational funding for the station.

Component Assessment

In the second step of the evaluation, the station conditions and alignments were assessed for each of these measures. The set of alignments and each set of station conditions were assessed separately, because the purpose was to determine the preferred option in each group. The participants in this assessment represented the relevant engineering, architectural, construction, and operations disciplines to ensure that knowledgeable input was provided.

The evaluation was conducted using indicators expressing the ranking of each option relative to the others within its group. The scale used was as follows:

+ +	Significantly better
+	Better
o	Neutral (or average)
-	Worse
—	Significantly worse

Neutral (or average) meant the component had no significant impact on that measure relative to the other components, or it fell into the middle of the ranking. NA was used in cases where the measure was not applicable to the alignment options.

Figure 4 shows the summary of the evaluation in a matrix form. The individual rankings represent the consensus of the task force established to conduct the alternatives evaluation.

The overall assessment for each set of components was as follows:

- *Shot Tower/Market Place Conditions.* Condition 2, the station straddling the Jones Falls Boulevard, clearly ranked as the preferred location for the Shot Tower/Market Place because it provided direct access to both sides of the Jones Falls Boulevard (perceived as a community barrier and safety factor), served the interest of both the business community and the Jonestown neighborhood and had no significantly worse adverse impacts compared to the other conditions.
- *Johns Hopkins Hospital Station Conditions.* Condition 8, with the mezzanine that provided a direct tie into the northern bus facility, the best access relative to the existing hospital and commercial activities, and access to the future hospital development west of Broadway, ranked as the preferred arrangement for the Johns Hopkins Hospital Station although Condition 6 also had certain attractive features as well.

	Station Condition									Alignment I			
	1 Baltimore M of JFB	2 Baltimore Straddle	3 Baltimore E of JFB	4 Diagonal E of JFB	5 Fayette E of JFB	6 Broadway N Oriented	7 Broadway (N) #15 Crossover	8 Broadway N Oriented	9 Broadway S Oriented	I Fayette	II Baltimore	III Baltimore Broadway	IV Baltimore Fayette
Construction and Cost													
Constructibility	-	0	0	+	0	0	0	0	+	-	0	+	0
Cost	0	0	-	0	-	+	+	-	-	0	0	0	0
Service Aspects													
Patronage	+	++	-	--	--	+	0	0	0	NA	NA	NA	NA
Passenger Convenience & Safety	+	++	-	--	--	+	--	++	0	NA	NA	NA	NA
Bus Passenger Interface	0	0	0	0	0	+	-	+	0	NA	NA	NA	NA
Bus Operations	0	0	0	0	0	0	0	0	--	NA	NA	NA	NA
Rail Operations	0	0	0	0	0	0	-	0	0	0	0	0	0
Traffic Impacts During Construction	0	-	0	+	--	--	-	-	0	-	0	0	0
Displacement/Relocation													
Residences	0	0	0	-	0	-	-	-	0	0	0	0	0
Businesses	0	0	0	-	0	-	-	-	-	0	0	0	0
Environmental Aspects													
Parkland/Historic Areas	0	0	0	-	0	0	0	0	0	0	0	0	0
Noise/Vibration	-	0	0	0	-	-	-	0	+	-	-	+	-
Anticipated Community Concerns													
Agencies	+	++	0	0	-	+	+	+	0	0	0	0	0
Neighborhoods	-	-	-	-	++	0	0	0	0	+	-	-	-
Business Community	++	+	-	-	-	+	0	+	0	0	+	+	+
Private Sector Participation	++	++	0	+	0	0	0	+	+	NA	NA	NA	NA

++ Significantly Better　+ Better　0 Neutral　- Worse　-- Significantly Worse　NA Not Applicable

FIGURE 4 Components assessment matrix.

Additionally, Condition 6 had a comparative cost advantage of approximately $3.5 million in terms of 1986 dollars. Thus, the preference for Condition 8 was tempered by the additional costs associated with it and Condition 6 was also considered as a preferred station condition at Johns Hopkins Hospital Station.

- *Alignments.* Alignment III was the preferred route of the extension, primarily because it was farthest from the Church Home Hospital operating suites on Fayette Street (vibration during construction issue), had distinct advantages in constructibility over other alignments, offered the greatest flexibility in selecting station locations, and had the least potential for noise and vibration to be transmitted to sensitive receptors without costly mitigating treatments.

Step 3: Alternatives Assessment

In this step of the assessment process, the preferred station conditions and alignments became the basis for the evaluation of the alternatives. A table listing the remaining alternatives, shown in Figure 5, provided columns for indicating by symbol the preferred station conditions and alignments as a result of the previous component assessment. The six alternatives that included the preferred Baltimore Street/Broadway alignment (Alignment III) received a symbol under the Alignment Assessment column. The four alternatives that contained the preferred Shot Tower/Market Place Station straddling the Jones Falls Boulevard (Condition 2) each received a symbol under the Shot Tower/Market Place Station Assessment columns.

In the instance of the Johns Hopkins Hospital Station Assessment column, symbols were shown for both the extended mezzanine option (Condition 8) and the north-oriented conventional station option (Condition 6). Although Condition 8 achieved a slightly higher rating than the preferred Johns Hopkins Hospital Station condition, the difference in rating between it and Condition 6 was minimal and, as indicated previously, it carries a higher comparative cost of about $3.5 million in 1986 dollars, which was of sufficient magnitude to warrant further consideration. Because these two station conditions were so close in overall assessment and were the only ones to receive a positive composite assessment in this group, the resulting preference for Condition 8 was not sufficiently strong enough to warrant automatic elimination of Condition 6 for this step in the process.

For the purposes of evaluating alternatives to arrive at a preferred alternative, any station condition that did not have at least a positive composite rating was considered as not acceptable for further consideration. On this premise, Station Conditions 3, 4, 5, 7, and 9 were therefore eliminated from further consideration.

In the case of the alignment options, the number of applicable evaluation factors was fewer and the relative differences between them were less pronounced. Consequently, although Alignment III was clearly the preferred option, because the cost differences between the alignments are minimal and the station conditions appear to be more dominant in selecting an alternative, no alignment was categorized as not acceptable at this time.

As can be seen from Figure 5, only Alternative III.A had a symbol in all three columns, which meant that it contained

Alignment	Alternative Description	Station Condition		Alignment and Construction Method	Market Place Station	Johns Hopkins Station	Comments
		Market Place	Johns Hopkins				
Fayette (Alignment I)	I.	5	6			■	
	I.A.	5	7				
Baltimore (Alignment II)	II.	1	6			■	
	II.A.	2	6		■	■	Lower cost range
	II.B.	3	6			■	
	II.C.	1	7				
	II.D.	2	7		■		
	II.E.	3	7				
Baltimore/Broadway (Alignment III)	III.	1	8	■		■	Higher cost range
	III.A.	2	8	■	■	■	Higher cost range
	III.B.	3	8	■		■	Highest cost Cond. 3 unacceptable
	III.C.	1	9	■			
	III.D.	2	9	■	■		Lower cost range Cond 9 unacceptable
	III.E.	3	9	■			
Baltimore/Fayette (Alignment IV)	IV.	1	6			■	
	IV.A.	4	6			■	
	IV.B.	1	7				
	IV.C.	4	7				

■ Preferred from Figure V-1

FIGURE 5 Alternatives assessment matrix.

all of the preferred elements: Baltimore/Broadway alignment (Alignment III) with a Shot Tower/Market Place Station straddling the Jones Falls Boulevard (Condition 2) and the extended mezzanine station (Condition 8) at Johns Hopkins Hospital. Consequently, it could be considered a preferred alternative.

However, by reference to Figure 3, it can also be seen that Alternative III.A has a comparative cost ($102,576) that is in the higher range of costs. It was decided, therefore, to review those alternatives that had only two symbols, a somewhat lesser preferability, but whose comparative costs were significantly lower. There were four alternatives that display two symbols, two of which had equal or higher comparative costs, one that had lower comparative costs but contained an unacceptable station condition and one that had lower comparative costs ($99,026), and both preferred station conditions with an acceptable, if not preferred, alignment. This last alternative was Alternative II.A.

The evaluation process thus far had reduced the number of contending alternatives from 24 to 18 to 2. Comparison between Alternatives III.A and II.A needed to be addressed with further investigations, as are discussed in the following section.

COMPARISON OF ALTERNATIVES II.A AND III.A

The assessment areas found to be significant in the comparison of Alternatives II.A and III.A are shown in Figure 6.

The first column of Figure 6 lists the assessment areas. The next column identifies those assessment areas that are believed to be important in making the comparisons between Alternatives II.A and III.A. The next two columns display the summary evaluation for Johns Hopkins Hospital Station Conditions 6 and 8. The last two columns are for the combination of station condition and route alignment. These last two columns also contain an indication as to which is the preferred alternative for that assessment area, wherever such a preference can be established.

It can be seen from Figure 6 that Alternative III.A was preferred from the standpoint of noise and vibration, because any negative impacts in this area should be easier to mitigate. This preference resulted from the fact that the track crossover for Alternative III.A is located further away from particularly sensitive areas such as the Wilmer Eye Clinic (where microsurgery is performed), and the alignment is further from the Church Home Hospital operating suite. On the other hand, the current comparative cost estimates indicated a preference for Alternative II.A because it was less expensive than Alternative III.A.

With respect to patronage, the analysis showed that Alternative II.A was better, but the additional potential patronage was so small as to discount this advantage to the point that the two should be considered virtually equal. The site conditions that help shape station configuration were such that Alternative III.A was preferred with respect to architectural and functional layout. Alternative III.A also offered somewhat better geological conditions for tunneling and consequently had less design and cost risks or uncertainties.

In terms of operating characteristics, Alternative II.A offers a shorter overall travel path of about 500 ft. This difference becomes a factor in train operating mileage when the line is extended north of Johns Hopkins Hospital Station because it represents additional car mileage for each one-way trip through this segment of the system. Alternative II.A also has an 80-ft shorter length of line from Charles Center Station to the end of construction. On the other hand, Alternative II.A has somewhat more curvature. The total angular direction change for Alternative II.A is about 143 degrees, versus 123 degrees for Alternative III.A.

Although both alignments require some underground easements for tunneling beneath private property, Alternative II.A was somewhat preferable because it avoided easements under Church Home Hospital. Discussions and negotiations for easements at Church Home Hospital would undoubtedly be time consuming, and would include consideration of indemnification against damages occurring during construction and operation. However, Alternative III.A offered an advantage in ease of mitigation noise and vibration due to the physical distances separating the alignment from sensitive areas such as the Church Home Hospital operating room and the Wilmer Eye Clinic. Finally, Alternative III.A was judged to be preferable to II.A with respect to adverse traffic impacts.

Overall, the cost advantage associated with Alternative II.A resulted in its selection as the preferred alternative. Subsequently, additional noise and vibration analyses were conducted and mitigation measures were developed to minimize noise and vibration impacts. This alternative has proceeded through final design, and construction was initiated in July of 1989. The extension, as shown in Figure 7, is scheduled for revenue operation in 1994.

SUMMARY

A procedure enables the evaluation of a large number of alternatives against a broad range of criteria and the identification of a preferred alternative, or at least a reduced set of alternatives and criteria that can be handled with a more traditional evaluation process. The essence of the procedure is to isolate significant differences among the alternatives by a sequence of disaggregation and aggregation of components and sets of alternatives, and identify where the clear preferences exist and where they do not. The procedure also promotes a clearer understanding of the evaluation criteria and the relative importance of each. In each step, only those criteria that differentiate the alternatives are applied.

This procedure reduces what could be a clearly unmanageable situation—in this example, 24 alternatives and dozens of evaluation criteria—to a series of steps that are not only manageable by the participants but also the results and procedure are presentable to others. This procedure has application to a broad range of transportation planning and design conditions. This general procedure has been applied in several other transportation planning projects. Recently, it was used to define a set of transit alignment options to carry into an AA/DEIS for an extension of the Baltimore Central Light Rail Transit Project. Here, the objective was not to select a preferred alternative, but only to reduce a large number of

		Station Condition		Stations and Alignments			
				6 + Alignment II		8 + Alignment III	
Assessment Area	Very Important?	6 Assessment	8 Assessment	Assessment	Prefer?	Comments	Prefer?
Noise and vibration	Yes	Not as good	Better	More Problem at JHH and Church Home Hospital	-	Better - Further from crossover	Yes
Comparative Cost	Yes	Less money	More money	(Basis for comparison)	Yes	$3-4 million more for line and station	-
Bus/Rail Transfer and Patronage	- Yes	Better	Not as good	Better, but difference is small	?	-	-
Architectural Function	-	Not as good	-	-	-	-	-
Operations	Length - Yes Curvature - Yes	-	-	Less, better path More Curvature	Yes -	Longer path Less Curvature	- Yes
Constructability	-	-	-	Not as good	-	Better geology - Less risk for tunneling	Yes
Easement Requirements	Somewhat	-	-	Better, but still a problem	Somewhat	Not as good because of Church Home	-
Ability to Mitigate	-	-	-	Not as good	-	Better	-
Traffic Construction Impact	-	Not as good	Better	-	-	-	-

FIGURE 6 Comparison of Alternatives II.A and III.A.

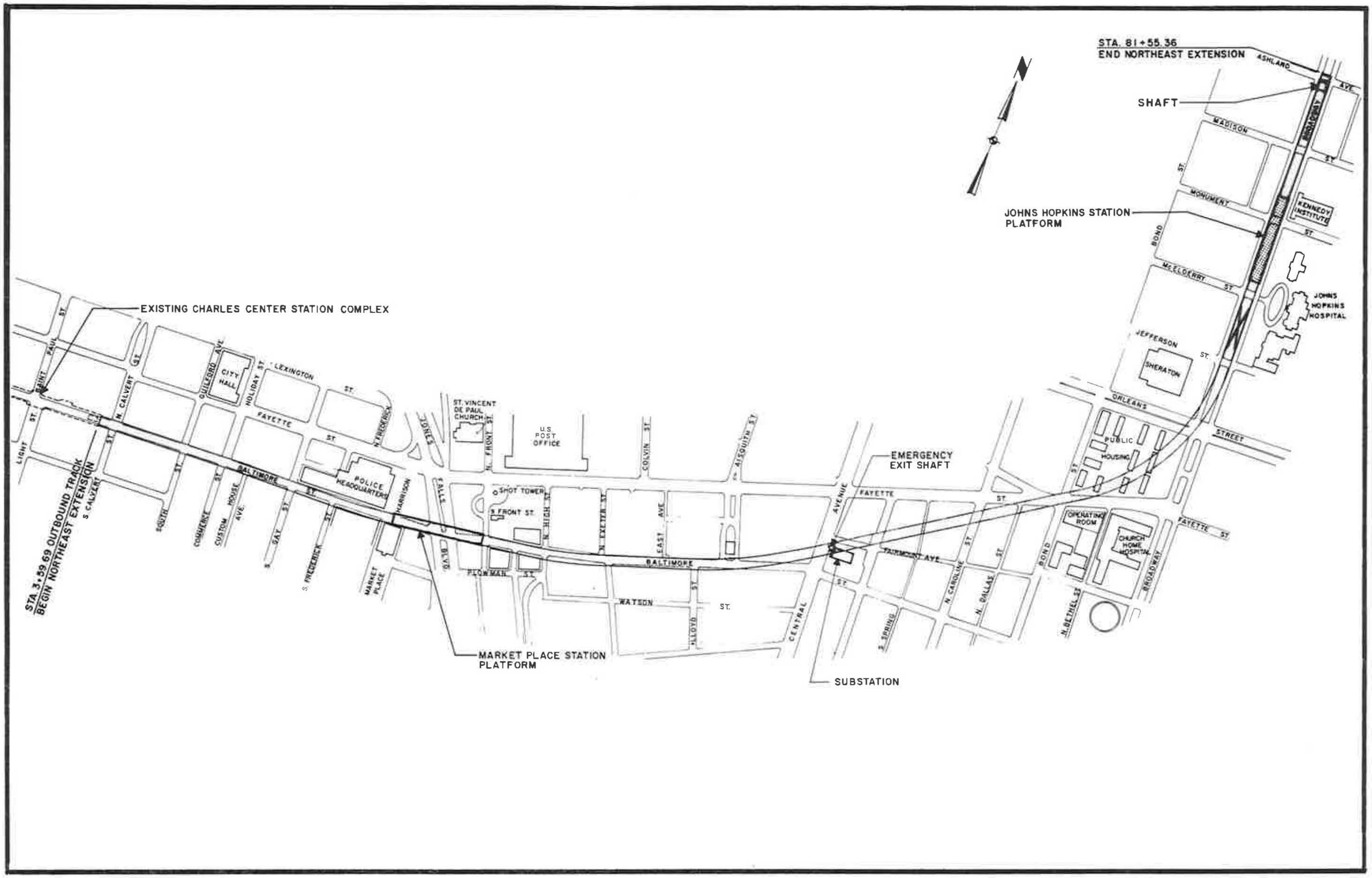

FIGURE 7 Baltimore Section C Metro extension.

options, many with mix-and-match components, down to a set of two to three alternatives that are to be subjected to more detailed analysis and evaluation during the alternatives analyses process.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of David Miller of Parsons, Brinckerhoff, Quade, and Douglas, Inc. and of Walter Kudlick of Kudlick Consultants, who helped develop the procedure, and to acknowledge the many participants in the procedure from the Maryland Mass Transit Administration and the Baltimore Metro Section C general engineering consultants DKP (Daniel, Mann, Johnson, and Mendenhall; Kaiser Engineers; and Parsons, Brinckerhoff, Quade, and Douglas, Inc.).

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Site Selection and Sizing of an LRV Storage Yard

RANDOLPH W. HALL

The San Francisco Municipal Railway (MUNI) is in the process of expanding its light-rail vehicle (LRV) system, to include track extensions and a new storage and maintenance facility. Methodology used by Manna Consultants to evaluate the operating cost savings (deadheading and driver relief costs) associated with alternative storage yard configurations and locations is described. A mathematical model was programmed on Lotus 1-2-3 to allow rapid analysis of alternative scenarios that were developed through conferences between Manna, MUNI, and the San Francisco Public Utilities Commission. The study determined that the new yard should be designed to accommodate LRVs only, and not a mixture of LRVs and historic streetcars, as had been proposed. For the current fleet, the new yard was found to reduce annual deadheading and relief costs by $1,000,000 per year. Although significant, this saving alone would not justify construction of a new storage yard. Justification comes from the need to store an expanded fleet that cannot be accommodated by the existing yards.

The City of San Francisco is planning an expansion of its light-rail vehicle (LRV) system, to include track extensions and an additional storage and maintenance facility. At present, the city's Municipal Railway System (MUNI) operates five LRV lines over 21 mi of track, carrying an average of 130,000 passengers per weekday. The route structure is radial, with lines heading west out of the downtown in a common subway, then splitting to run separately along the surface on the western side of the city.

All LRVs are now stored and maintained at the Metro Center and Geneva yards, which are located adjacent to each other at the western terminus of the J, K, and M lines as shown in Figure 1. The yards have a nominal capacity of 135 vehicles combined, but are currently operated above capacity to accommodate the LRV fleet of 130 vehicles along with a fleet of 30 historic streetcars (which are only used during special streetcar festivals).

Manna Consultants was engaged by the San Francisco Public Utilities Commission (SFPUC) to design and evaluate a new storage and maintenance facility—Metro East—to be located on the eastern side of the city, in the vicinity of the downtown. Metro East would be near the terminus of a track extension planned to serve locations south of the downtown, including the Southern Pacific Railway commuter terminal and a major new real estate development. The purpose of Metro East is two-fold:

1. To provide space to store and maintain an expanded fleet, including vehicles needed to cover
   —The LRV track extension,
   —Headway improvements on existing lines, and
   —A new full-time historic surface streetcar line along Market Street.
2. To reduce operating costs associated with positioning vehicles and drivers on lines that are distant from the existing yards.

A flexible model was developed to evaluate the operating cost savings taking into account yard size, configuration, and location. A crucial decision was whether the new yard should both accommodate the historic streetcars and the LRVs, or whether it should be dedicated to the LRVs. Because a mixed facility would require additional investment, it would have to be justified by operating cost savings. A second issue was whether the new yard could provide substantial cost savings on the existing L and N lines, which do not terminate near the existing Metro Center and Geneva yards.

The methodology was adapted from prior work on selecting bus garage sites (*1–5*). In many respects, the issues are the same for buses and LRVs. For both, facilities should be situated close to the points where vehicles begin and end their blocks (the series of runs performed by a vehicle during a day). To evaluate any combination of sites, each block is assigned to the site that minimizes operating costs, given restrictions on storage capacity. The total operating cost, along with site-specific costs, is then a basis for comparing alternative plans.

The added complication with LRVs is that it is difficult to identify the precise starting and ending points of blocks. At MUNI, as with many other LRV systems, vehicles are considered to be in revenue service from the moment they leave the yard until the moment they return. One might argue, then, that all blocks begin and end at the existing yards. But this perspective is unduly biased against new locations: the optimal place for any new yard would have to be the same location as the existing yard, because this policy would minimize the distance to start and end points. Clearly, some point other than the existing yard should be selected for starting and ending blocks. But where?

DELINEATION OF FIXED AND VARIABLE COSTS

The approach was to divide operating costs into two categories, those that were fixed with respect to yard locations, and those that varied with respect to yard locations. The analysis sought to evaluate only the variable costs.

Delineating the fixed from the variable costs was a matter of considerable discussion between MUNI, SFPUC, and

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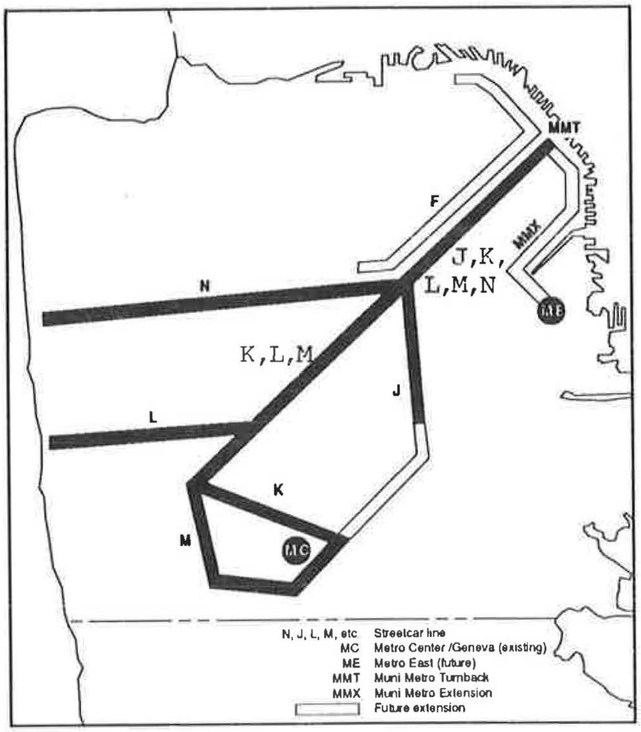

FIGURE 1 Map of MUNI Metro LRV System, showing added MMX Line. Inner terminal is MUNI Metro Turnaround (MMT), or Embarcadero.

Manna. In the meetings, a variety of reasonable perspectives was expressed. The following is something of a middle ground, agreeable to all.

Blocks were first divided into two categories: (a) base service, and (b) supplemental service. Blocks in the first category serve both the a.m. and p.m. peaks, as well as the midday period, usually with one or more driver relief. Blocks in the second category serve only the a.m. or only the p.m. peak (there are roughly equal numbers of both), and do not require a driver relief. All blocks on Saturday and Sunday fell in the base category, whereas Monday to Friday had a mixture of base and supplemental blocks.

For the a.m., blocks were designated to begin either at an outer terminal (the line terminus away from the downtown) or the inner terminal (the terminus in the downtown). The number of blocks beginning at the inner terminal was set to equal the number of vehicles needed to provide a minimum outbound headway of 20 min at the start of the day. Because the running time from inner to outer terminal was roughly 40 min on each line, and because vehicles operate in two-car trains, this meant four blocks were designated to begin at the inner terminal on most lines. After the first 40 min, outbound runs could be covered by trains arriving from the outer terminal. All remaining blocks were designated to begin at the outer terminal, to provide shorter headways for inbound service during the morning peak.

In the evening, the process is reversed for base service, the ending points being identical to the a.m. starting points. For supplemental service during the a.m. peak, all blocks were assumed to end at the inner terminal. Because the purpose of the supplemental service is to provide inbound capacity, vehicles would cease to be productive once they completed their last run to the inner terminal. Supplemental service for the p.m. peak is the mirror image of that for the a.m. peak. Blocks begin at the inner terminal at the start of the rush, and end at the outer terminal.

From the standpoint of minimizing deadheading, it is advantageous for blocks to begin and end at the same location. Therefore, it was decided that, where possible, the blocks beginning at the inner terminal should be supplemental vehicles. (The exception was the M line, which does not provide supplemental service.) This policy allowed supplemental vehicles to be stored at Metro East, enter service at the inner terminal, and leave service at the inner terminal.

The proposed track extension (MMX in Figure 1) was treated in the same way as existing lines, with its inner terminal located downtown and its outer terminal located away from downtown (in this case south instead of west). There was some discussion as to whether or not the extension should be treated independently, for it would in fact be operated as an extension of the existing N line. It was concluded that the extension should be treated independently. The predominant travel on the extended N line would be toward the downtown, but it would come from two distinct directions—from the east on the existing line and from the south on the extension. Therefore, vehicles would have to begin service from distinct outer terminals.

COST TYPES

Two types of variable costs were included in the analysis: (a) deadheading costs, and (b) driver relief costs. Deadheading costs were evaluated for each block by calculating the travel time from each yard site (including the current site) to each of the block's terminals (starting and ending), and multiplying by an hourly cost (accounting both for vehicle and driver costs).

Relief costs were calculated by multiplying driver travel time to and from relief points (line running time plus ½ headway, as specified in MUNI's labor contracts) by hourly compensation. Relief costs are incurred when a driver's run begins and ends at different locations. For base service, these costs occur on vehicles that do not return to their storage yard during the course of the day (currently, the L and N lines; see Figure 1), because driver exchanges cannot occur at the vehicle's home base. For these lines, relief costs are incurred exactly twice per day, when the first driver of the day returns from the relief point to the storage yard, and when the last driver of the day travels from the storage yard to the relief point. The relief was assumed to occur at the point on the line that is closest to where the vehicle is stored.

For supplemental blocks, relief costs are only incurred when a vehicle is stored overnight at Metro Center/Geneva, on the western side of the city, and stored during the middle of the day at Metro East, in the vicinity of the downtown. (It would never be desirable to do the reverse—Metro East overnight, Metro Center/Geneva midday—because the predominant direction of travel is toward Metro East in the morning, and away from Metro East in the evening.) At the expense of somewhat higher driver compensation, this policy would reduce deadheading costs at the end of the a.m. peak, and at the start of the p.m. peak. Relief cost was calculated on the basis of the travel time between the yards, multiplied by driver compensation.

A third relevant cost, which was not included, was compensation for split shifts. MUNI believed that their compensation scheme was too complicated to incorporate in a planning model, that part-time drivers would cover many of the supplemental routes, and that travel relief costs would reflect much of the split-shift costs.

These costs comprise the variable portion of the system costs. All remaining costs, such as the cost of operating the blocks themselves, were assumed to be fixed, and were not included in the calculations. An attractive feature of this approach was that it was not necessary to make any assumptions as to the number of runs or the length of time in each block. This cost would be independent of the yard location.

EVALUATION APPROACH

To summarize, for any possible site for Metro East a plan had to be devised for storing vehicles. For base service, a vehicle (represented by a block) could either be stored at Metro East or at Metro Center/Geneva. For supplemental service, a vehicle could be stored at Metro East or at Metro Center/Geneva, or it could be stored at Metro Center/Geneva overnight and at Metro East at midday. The choice was based on variable costs, taking into account both deadheading and relief costs, and also taking into account yard capacities.

For each site considered, a matrix representing the costs of assigning each block to each yard was generated in Lotus 1-2-3. The Lotus 1-2-3 model provided flexibility to quickly compare alternative sites. A single entry represented the travel time from the new yard to the downtown terminus of all lines. By changing this single entry (i.e., by moving the yard either closer or further from the terminus), a new cost matrix would be automatically generated. A new cost matrix could also be generated if the driver compensation or vehicle operating cost changed, also through adjustment of single entries.

The Lotus 1-2-3 model was set up to assign vehicles to yards and generate cost estimates, for the following scenarios:

Scenario	*Description*
Unrestricted	Expanded fleet, without restriction on storage capacity.
Scenario 1	Expanded fleet, with storage capacity for 90 LRVs at Metro East, 90 LRVs at Metro Center, and 45 historics at Geneva.
Scenario 2	Expanded fleet, with storage capacity for 45 LRVs and 45 historics at Metro East, 90 LRVs at Metro Center, and 45 at Geneva.

The number of active vehicles to be assigned is provided in Table 1. It was assumed that for every four LRVs assigned to a yard, one additional space would be allocated for a reserve vehicle. Therefore, a yard capacity of 90 LRVs would translate into an active fleet of 72 vehicles and a reserve fleet of 18. For the historic cars, two reserve vehicles were needed for each active vehicle. This unusually large ratio was because of higher maintenance requirements, and the need to store special vehicles (including open-air cars) that would only be used occasionally. Therefore, a yard capacity of 45 historic cars translated into an active fleet of 15 vehicles and a reserve fleet of 30 vehicles. In total, 159 active vehicles and 66 reserve vehicles had to be assigned to 225 spaces.

Calculating the unrestricted cost was simply a matter of choosing the least cost location for each block, and summing the costs. This resulted in the minimum possible operating cost, but demanded that more vehicles be stored at Metro East than it could accommodate. For the two restricted scenarios, some of the LRVs had to be reassigned from Metro East to Metro Center/Geneva. This reassignment was accomplished by selecting the blocks for which the cost difference between the two locations was smallest (in cases where several new locations are being considered, this could be accomplished by solving a transportation problem through linear programming). Under Scenario 2, some of the historic cars also had to be reassigned from the existing yard to Metro East.

TABLE 1 ACTIVE VEHICLES BY LINE

Active Vehicles by Line

	CURRENT				PROPOSED(1)			
	Peak(2)	Midday	Sat	Sun	Peak	Midday	Sat(3)	Sun(3)
F	0	0	0	0	15	9	6	5
J	12	7	4	4	19	11	6	6
K	18	9	7	6	20	10	8	7
L	23	9	9	7	33	13	13	10
M	20	20	8	7	22	22	9	8
N	29	18	12	9	34	21	14	11
MMX(4)	0	0	0	0	16	10	6	5
TOTAL	102	63	40	33	159	96	62	52

(1) Based on Metro Turnaround study. J line adjusted upward by 3 to cover extension. L line adjusted downward by 5, to resolve discrepancy with current service, and to attain total LRV fleet of 144, or 80% of total LRV fleet size of 180.

(2) Current peak is average of a.m. and p.m. service

(3) Assumes same as % drop on Sat and Sun as current

(4) MMX: Muni Metro extension to Metro East

Both actions result in a cost increase over the unrestricted solution.

Table 2 presents a sample output from Lotus 1-2-3 for one of the yard locations considered. In the data section of the spreadsheet, the travel time from Metro East to the inner terminal, the operating cost per vehicle-hour, the driver compensation per hour, and the number of runs that begin at the inner terminal (Embarcadero) are specified by the user. Total costs are calculated internally and summarized in the results section.

In the cost analysis section of the spreadsheet, costs are calculated on a line-by-line basis. First, costs are calculated for base service from the outer terminal, then for peak service, and finally for base service beginning at the inner terminal (Embarcadero). For each type of block, costs are calculated for each storage option: Metro Center/Geneva or Metro East for base service and inner terminal service, and Metro Center/Geneva or Metro East or Metro Center/Geneva night plus Metro East day for peak service. The minimum cost solution is selected, subject to restrictions on yard capacity. The detailed costs are summed to obtain the summary costs already mentioned. Not shown are additional data on the number of vehicles by line and yard capacity.

RESULTS

From the standpoint of operating costs alone, Metro East was found to be a better place than Metro Center/Geneva for storing the following types of vehicles:

- All service beginning or ending at the inner terminal (Embarcadero),
- Midday only storage of all supplemental service,

TABLE 2 SAMPLE OUTPUT FROM LOTUS 1-2-3 SPREADSHEET EVALUATING EXPANDED FLEET

```
SUMMARY       EXPANDED

DATA          TT to ME            12 min
              Oper Cost           70 $/hr
              TT Cost             23 $/hr
              # Emb Start          4

RESULTS       Unrestricted     57283 $/week
              Scenario I       61504 $/week
              Scenario II      67058 $/week
--------------------------------------------------------------------------------------------
COST ANALYSIS

TOTAL COST -- BASE SERVICE ($/wk)     DH COST -- BASE SERVICE ($/wk)     TT ALLOWANCE -- BASE SERVICE ($/wk)
        MC/Gen    ME    Min                   MC/Gen    ME    Min                   MC/Gen    ME
     F   4372   4803   4372              F    3136   4125   3136              F    1236    678
     J      0   6964      0              J       0   6195      0              J       0    769
     K      0   6728      0              K       0   5985      0              K       0    743
     L   8035   8976   8035              L    6440   7933   6440              L    1595   1043
     M      0  11685      0              M       0  10395      0              M       0   1290
     N  17702  13949  13949              N   14803  13949  13949              N    2900      0
   MMX   7606      0      0            MMX    6251      0      0            MMX    1355      0
 TOTAL  37714  53105  26355          TOTAL   30630  48582  23525          TOTAL    7085   4523

TOTAL COST -- PEAK SERVICE ($/wk)     DH COST -- PEAK SERVICE ($/wk)     TT ALLOWANCE -- PEAK SERVICE ($/wk)
        MC/Gen    ME  MC-ME     MIN           MC/Gen    ME  MC-ME     MIN           MC/Gen     ME  MC-ME
     F   3220   2147   2569    2147      F    3220   2147   1680    1680      F        0      0    889
     J   1680   2660   1449    1449      J    1680   2660    560     560      J        0      0    889
     K   2520   3990   2174    2174      K    2520   3990    840     840      K        0      0   1334
     L  13160  10173  12237   10173      L   13160  10173   8680    8680      L        0      0   3557
     M      0      0      0       0      M       0      0      0       0      M        0      0      0
     N   9240   6405   8721    6405      N    9240   6405   6720    6405      N        0      0   2001
   MMX   3873    560   3643     560    MMX    3873    560   2753     560    MMX        0      0    889
 TOTAL  37714  53105  30794   22908  TOTAL   33693  48582  23525   18725  TOTAL        0      0   9560

TOTAL COST -- EMB  SERVICE ($/wk)     DH COST -- EMB  SERVICE ($/wk)     TT ALLOWANCE -- EMB  SERVICE ($/wk)
        MC/Gen    ME    MIN                   MC/Gen    ME    MIN                   MC/Gen    ME
     F   2582    724    724              F    2487    672    672              F      95     52
     J   3997   1448   1448              J    3967   1344   1344              J      31    104
     K   3997   1448   1448              K    3967   1344   1344              K      31    104
     L   4126   1448   1448              L    3967   1344   1344              L     159    104
     M   2317    888    888              M    2287    784    784              M      31    104
     N   4157   1375   1375              N    3967   1344   1344              N     190     31
   MMX   2078    687    687            MMX    1983    672    672            MMX      95     15
 TOTAL  23256   8019   8019          TOTAL   22624  48582  23525          TOTAL     632    515
```

- All service on the new Metro Extension and the N line, and
- Supplemental service on the F and L lines (both overnight and midday).

These vehicles (110 in total) constituted the unrestricted solution, which exceeded the planned Metro East capacity by 20 vehicles. Comparing Scenario 1 to Scenario 2, it was concluded that it would not be worthwhile to accommodate the historic cars at Metro East, because of the small number of historic cars that should be assigned there. Subtracting these, 102 LRVs were left for Metro East, or just 13 percent more than the planned capacity. Of these 102 vehicles, 12 were reassigned to Metro Center/Geneva, to meet the target yard size of 90 vehicles. This solution is shown in Figures 2 and 3. In Figure 3, for each line, blocks are classified by inner versus outer terminal, and base versus supplemental (MC = Metro Center/Geneva, ME = Metro East, MC/ME = Metro Center/Geneva night and Metro East day). Fortunately, it was found that a redesign of Metro East would provide sufficient space for 12 more cars. Therefore, the current plan provides for a full 102-vehicle capacity. The projected variable cost for this plan amounts to $60,000 per week, which is $7,000 per week less than Scenario 2.

The analysis was designed to compare the relative merits of alternative locations and configurations, not to measure the cost effectiveness of building a new yard. Nevertheless, for the current fleet size, the savings in deadheading and relief costs were found to be $1,000,000 per year. Clearly these savings alone could not justify the project. The primary motivation for Metro East is that the existing storage yards are too small to accommodate an expanded fleet and that it would be more expensive to expand the existing yards than to build a new yard at an alternative location.

To a great extent, the study confirmed the expectations. Metro East would be a good place to store vehicles that begin and end their runs away from the existing yards. The N line, the new Metro Extension, and all runs beginning at the inner terminal were obvious candidates. A less obvious choice was the supplemental L service, whose outer terminal is closer to Metro Center/Geneva, but whose inner terminal is closer to Metro East. Through analysis, it was found that by storing the vehicles at Metro East, both midday and overnight, MUNI could eliminate the driver relief cost of $3,600 per week, and that this saving would more than compensate for a slight increase in deadheading costs of $1,500 per week.

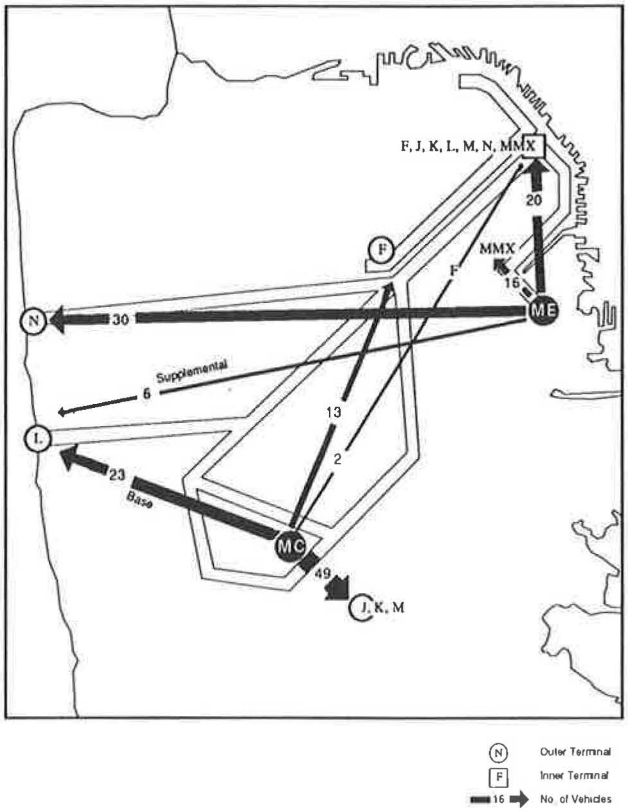

FIGURE 2 Assignment of active vehicles to yards for weekdays; 72 active vehicles are stored at Metro East and 87 active vehicles are stored at Metro Center/Geneva.

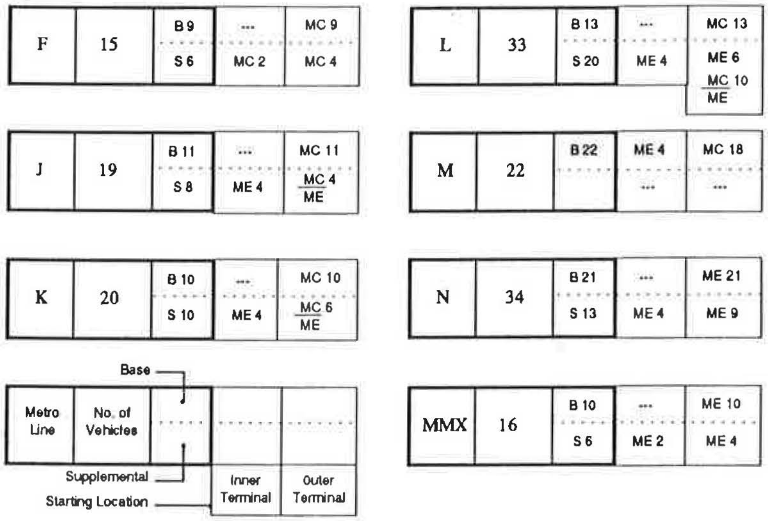

FIGURE 3 Assignment of blocks to yards for weekdays.

Most of the L line vehicles should continue to be stored at Metro Center/Geneva, because the outer terminal of the L line is closer to Metro Center/Geneva than to Metro East. Also, cost savings from storing the N line vehicles at Metro East are not enormous (under $10,000 per week), despite the fact that the N line operates far from Metro Center/Geneva. The reason is that the outer terminal of the N line is only slightly closer to Metro East (49 min) than it is to Metro Center/Geneva (52 min). Combined, these facts indicate that Metro East is a far from optimal location from the standpoint of deadheading/relief costs for existing lines. A preferred location would be on the western side of San Francisco, near the outer terminals of the L and N lines. However, there are few feasible sites there, or for that matter, anywhere else in San Francisco. Within the South of Market Area, on the other hand, there are several options. The analysis allowed comparing the operating costs for these alternatives as an input to the site selection process.

A weakness in the analysis is that all costs are assumed to vary proportionately with the number of deadheading hours and the number of driver travel hours. In reality, work rules might prevent a savings of an hour here or an hour there from being translated into real cost reductions. Unless the number of drivers (and, perhaps, vehicles) is reduced, costs may remain more or less the same. Unfortunately, the number of drivers is dictated more by the number of vehicles needed to cover the peak-period demand than by deadheading that occurs before or after the peak periods. Nevertheless, even if direct cost savings do not materialize, service improvements will. Therefore, the cost evaluation is a suitable way to compare alternatives.

Finally, returning to the issue that vehicles are actually in revenue service whenever they are outside the yard, reducing deadheading must also reduce some types of service. For instance, our proposal reduces service in the morning, heading from the existing yards to the outer terminals of the L and N lines (by 6 and 30 runs, respectively). However, few people benefit from this service, which is why the cost of these runs is allocated to deadheading. At the same time, the proposal increases outbound service from the downtown in the early morning (i.e., deadheading to outer terminals of L and N lines). This service will likely benefit few people, which is why it is also put in the deadheading category.

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Modernization of SEPTA's Norristown High-Speed Line

J. William Vigrass

The Norristown High-Speed Line (NHSL) is an interurban electric railway connecting the western terminus of Southeastern Pennsylvania Transportation Authority's (SEPTA's) Market-Frankford subway and elevated line at 69th Street, Upper Darby, with Norristown, a distance of 13.4 mi. En route, the NHSL serves 22 stations located in Delaware and Montgomery counties. The NHSL rehabilitation and modernization projects, as currently approved or planned for funding, involve the acquisition of 26 new multiple-unit electric interurban passenger cars capable of 70 mph (all of which will be equipped with cab signals and overspeed protection); capital spare parts for the cars; installation of a new wayside signal system that is compatible with the new cars and provides cab signal information to the motorman and overspeed command to the vehicle propulsion and braking control system as well as automatic and remote control of interlockings; reconstruction of most of the track system; rebuilding of two major passenger terminals; replacement of three electrical substations; rehabilitation of several bridges; creation of a new vehicle maintenance and repair facility; rehabilitation and enlargement of intermediate passenger stations along the line; construction of new pedestrian bridges to replace old ones; and the construction of new or expanded parking facilities for patrons at passenger stations. Accomplishment of this program should enable SEPTA to present a substantially improved level of safety and quality of service to existing and potential NHSL patrons for the 1990s and into the next century. During the period 1972–1988, UMTA had awarded approximately $110 million in federally funded grants to accomplish $153,000,000 in various capital improvement projects related largely to the NHSL. Additional funding is anticipated to complete the intended projects that are part of the overall program.

The Norristown High-Speed Line (NHSL) (Figure 1) and its modernization program are described. The line has a number of unique features and could be a model for others to emulate.

All other electric railways categorized as light rail are designed for medium speeds, generally 45–55 mph maximum. In contrast, the new Norristown cars are designed to operate at 70 mph, yet the line has 22 stations in its 13.4-mi length. End-to-end running time of 22 min (presently 30 min) is planned.

The application of the term "light rail" to the NHSL is done purposefully. The line opened in 1907 as an interurban electric railway. It operated mostly one-car trains, with some two-car trains. At the end of its corporate existence, it legally became a street railway for 1 year before being merged into a company having a street railway charter. Although its physical plant may appear to be similar to some heavy-rail lines in that it is fully grade separated and uses third rail and high platforms, it is its character of operation that places it in the light-rail category.

The NHSL's technology and operating practices might be applied to new rail transit lines built on abandoned or underutilized railroads in urban or suburban areas where its type of fast, frequent service with one- or two-car trains might be appropriate.

HISTORY

A brief history of the NHSL is appropriate for explaining some of the reasons for that line's unique features. A complete history of the NHSL has been given by Degraw (*1*).

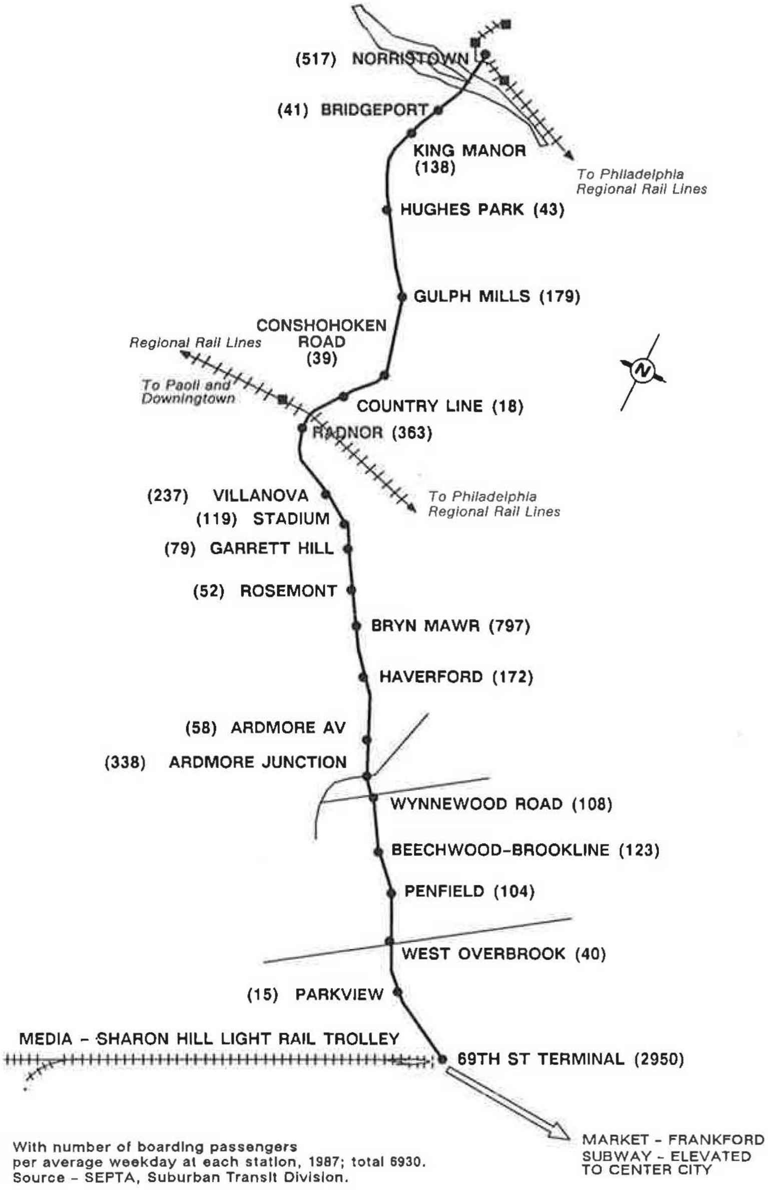
The Philadelphia and Western Railroad (P&W RR) Co. was incorporated as a steam railroad in 1902 by financial interests secretly related to George Gould's transcontinental railroad scheme. George had inherited control of the several western railroads when his father, Jay, died in 1892. George began to build a transcontinental system based on the Missouri Pacific, Wabash, and Denver & Rio Grande Western (D&RGW) stretching from Ogden, Utah, to Toledo, Ohio. He built the Western Pacific (WP) from Ogden to Oakland, California, using the D&RGW's earning power to guarantee WP's bonds. Control of the Wheeling and Lake Erie railroad connected Toledo with Pittsburgh Junction, Ohio, near Wheeling, West Virginia. From there, heavy construction was needed, so Gould formed the Wabash-Pittsburgh Terminal Railroad to enter Pittsburgh and build a hilly extension to Connellsville, Pennsylvania, for a connection with the Western Maryland, which he controlled. The Gould rail empire stretched from Baltimore, Maryland, on the Atlantic Ocean to Oakland, California, on the Pacific Ocean.

The seemingly independent Philadelphia and Western (P&W) was incorporated to build from 63rd Street in western Philadelphia to Parkesburg, Pennsylvania, about 44 mi. The secret plan was to quickly complete the P&W to Parkesburg, then suddenly build on to Lancaster and York, Pennsylvania, connecting with the Western Maryland at the latter point.

By the end of 1906, Gould was in financial trouble and had to give up his eastern objectives. The panic of 1907 and other events caused most of his railroads to be in bankruptcy by 1908, and his dream of a great coast-to-coast railroad collapsed. The P&W stood alone.

The P&W's directors had inquired about steam locomotives, passenger, and freight cars on two occasions, 1902 and 1903, but did not place any orders. In 1905, they decided to operate as an electric interurban railway when it became evident that the Gould plan was failing, and 22 electric interurban cars were ordered from St. Louis Car Company for delivery in 1907.

Hill International, Inc., One Levitt Parkway, Willingboro, N.J. 08046.



With number of boarding passengers per average weekday at each station, 1987; total 6930. Source - SEPTA, Suburban Transit Division.

FIGURE 1 Norristown High-Speed Line.

The P&W RR Co. had been reorganized in 1907 as the P&W Railway Company to allow additional stocks and bonds to be issued. Their efforts were sufficient to allow completion of the line as far as Strafford, Pennsylvania, 10.6 mi from the then-new 69th Street Terminal of Philadelphia Transportation Company's Market Street subway and elevated line to Center City and the ferries.

The line opened to Strafford in 1907. In 1912, the Norristown Branch, 6.5 mi, was opened as a key link in the Philadelphia-Allentown Lehigh Valley Transit Company's interurban line. The Norristown Branch quickly became the functional mainline, whereas the Strafford line remained lightly used and became a branch.

The steam railroad origin left a legacy of a double-tracked, grade-separated railway, with a maximum grade of 2.5 percent, and maximum curvature of 5 degrees. This was substantially better than typical interurban electric railways of that period. An 8-degree curve at Villanova Junction was added in 1912 when the Norristown Branch was built.

The P&W was modernized in the years 1930–1933, under the direction of Dr. Thomas Conway, Jr., a former Professor of Finance at the University of Pennsylvania's Wharton School. He had established a reputation of transforming financially ailing interurban railways into profitable enterprises. Under Conway's direction, track was upgraded with superelevation of curves increased to 8 in. to allow speeds of 80 mph. Signals, substations, and passenger stations were modernized. During 1924 to 1928, 11 cars built, Nos. 60 to 70, were modernized by increasing motor horsepower from 60 to 100, which increased their speed from a modest 44 to 60 mph.

More important, 10 new cars, the design features of which would be a major advance, were ordered. Conway sought a car that would be the fastest possible for the P&W's demanding profile, yet be economical to operate, and attractive to passengers. Conway realized that if the P&W was to compete with the newly electrified railroads and the ever-increasing number of automobiles, the P&W would have to provide all of the time savings in the interline trip with Philadelphia Rapid Transit Company's (PRT) Market-Frankford subway and elevated line. The latter operated what were probably the slowest rapid transit trains in the United States; they seldom exceeded 25 mph, and PRT had no plans to speed up its service. The P&W had to do it all.

Substantial research went into the new car design. Dr. Felix Pawlowski, Guggenheim Professor of Aeronautics at the University of Michigan, ran wind tunnel tests on more than 30 car body designs. The result of his tests was that his streamlined design would consume 43 percent less power at 70 mph than a conventional box car of similar size.

The new cars were 52 ft. 2 in. long, 9 ft. 2 in. wide, and only 10 ft. 6 in. high, had parabolic streamlined ends, low floors, skirting for both appearance and airflow, and a distinctive roof end that curved down over the cab. The aluminum body helped keep weight down to 52,200 lb. The cars had four GE706 motors of 100 hp each, which drove the car at a speed of 83 mph on straight, level track on 600 volts. However, P&W increased its third-rail voltage to 730 volts to enhance performance still more, with higher speeds having been reported.

Their appearance quickly earned the name "Bullet," a fitting label for what was the first aluminum-bodied, aerodynamically designed railway car in the United States. The Bullets of 1931 preceded the Burlington Railroad's Zephyr by several years, and were without question the fastest suburban rail cars.

The 10 Bullets and the eleven 60s (later 160s) provided all P&W service until recent years. The 60s normally provided Strafford local service until that line was abandoned in 1956. They also customarily provided Bryn Mawr and Wynnewood Road local service. The Bullets were almost always used on Norristown Express runs, which for many years were completed in 21 min.

The P&W shares and bonds were acquired by the Philadelphia Suburban Transportation (PST) Company's Red Arrow Lines in 1948, and P&W was merged into PST's corporate structure in 1953. The P&W Railway Company had been reorganized June 17, 1946, and again became the Philadelphia and Western Railroad Company. To allow merger of the P&W Railroad Company with its steam railroad charter into the Philadelphia Suburban Transportation Company, which operated under a street railway charter, the Philadelphia and Western Street Railway Company was incorporated on May 5, 1925. On December 31, 1952, it acquired the assets of the P&W Railroad Company, which then ceased to exist. On December 31, 1953, the P&W Street Railway Company was merged into the PST Company.

Southeastern Pennsylvania Transportation Authority (SEPTA) became a transit operator on September 30, 1968, when it acquired the assets and business of the Philadelphia Transportation Company. SEPTA had previously subsidized the commuter railroads of Philadelphia through operating agreements. SEPTA took over PST on January 29, 1970, and thereby acquired what had been the P&W. The latter was identified by SEPTA as its Route 100—the NHSL.

The line operated relatively routinely until the latter 1980s. Although its equipment was old, it was not scheduled for replacement because SEPTA had more urgent items needing immediate attention. However, in 1985 to 1986, several events occurred that caused the NHSL to be shut down for several months. A number of cars suffered electrical fires as a result of deteriorated insulation. Several other cars were involved in accidents, including one that rammed a bumping post at the 69th Terminal and penetrated the cinder block wall of the waiting room. The number of operable cars fell so low that operation could not be sustained, and the line was shut down in August 1986. Reduced service was resumed in October as several cars were repaired, but the inner part of the line was served by buses. Ridership plummeted.

SEPTA's Rail Equipment Department surveyed the industry for available used cars that could be operated on the NHSL. Of the few types available, the Chicago Transit Authority's Type 6000 was selected, and 10 married pairs were obtained. Seven were modified slightly and given a light overhaul, and five pairs were placed in service December 1986, which allowed full service to be restored. Two more pairs were put in service later and three were stripped for parts. In 1988, five Bullets and two 160s were also available, but one 160 failed in early 1989.

In the early 1980s, SEPTA staff decided that major renovation of the NHSL would be necessary. The NHSL Recapitalization Task Group was formed May 24, 1984; it was sometimes referred to as the "P&W Committee."

By 1985, the significant decisions had been made, and a list of projects was drawn that included vehicles, shop and yard, track (including third rail), substations, signals, stations, and parking. Passenger terminals were added to the program, and a complete program to rehabilitate or replace bridges was begun. Consultants were engaged to write specifications for certain projects, while SEPTA staff prepared others. A major in-house effort was the car specification.

Funding needs were estimated by SEPTA staff, and a capital program was laid out that covered a number of years. These estimates were the bases of capital grants. The entire program was envisaged as a number of independent projects. No full funding agreement for the program was sought because SEPTA staff had to fit NHSL projects in among many other high-priority projects. It was recognized that certain NHSL projects must be done in sequence and that certain projects had a direct relationship with others. A coordinating committee was established to handle such situations.

Each project has been a separate line item in a grant application or an individual grant. Some projects include funds from several grants.

THE PROGRAM

Table 1 presents a summary of system investments for the years 1976 through 1992, by use of which the following projects will be completed.

Cars

A total of 26 new, multiple-unit, interurban passenger cars will be acquired, including capital spares, at a cost of $55 million. The new cars (see Figure 2) have been designated as SEPTA Type N–5 because they will be the fifth car type to

TABLE 1 SUMMARY OF SYSTEM INVESTMENTS

System Component	Capital Funds	Operating Funds	Total
Car Renovations/Replacement	$ 54,862,980	$750,000	$ 55,612,980
Maintenance Facility Renovations/Replacement	21,337,020	60,000	21,397,020
Track Renewal Program	19,618,000	619,000	20,237,000
Substation Modernization	8,608,000	-0-	8,608,000
Signal System Modernization	15,213,000	-0-	15,213,000
Bridge Improvements	7,230,000	125,000	7,355,000
Stations & Parking Improvements	-0-	214,500	214,500
69th St. Terminal Improvements	14,750,000	-0-	14,750,000
Norristown Transportation Ctr.	11,700,000	-0-	11,700,000
TOTAL	**$153,319,000**	**$1,768,500**	**$155,087,500**

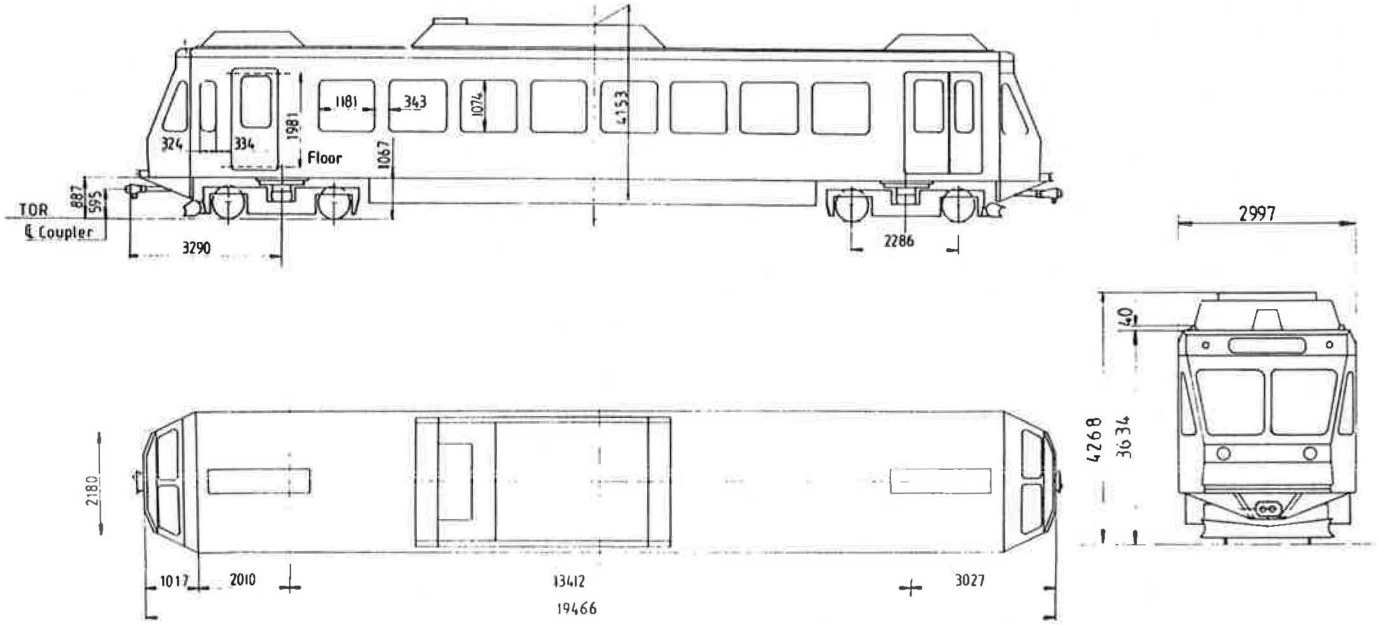


FIGURE 2 General arrangement of car as of October 20, 1989 (dimensions in millimeters).

have served the Norristown line since it opened in 1912. They will succeed the 1931 Brill Bullets and the 1924 to 1928 160 class Brill Strafford cars. The latter, of which No. 162 is the last remaining operable car, may be the oldest rapid transit car type in regular (nonhistoric) revenue service in the United States. The cars will have a stainless steel body 65 ft. 2 in. long, 9 ft. 10 in. wide, and 14 ft. 0 in. high. Trucks will be 7 ft. 6 in. in wheelbase, with truck centers 44 ft. 0 in. Weight should be about 70,000 lb. The car body is the largest that could be fit into the NHSL's clearances without major changes in wayside structures. Some minor changes will be necessary to accept the new cars. The 1931 Brill Bullet cars are 55 ft. long, 9 ft. 2 in. wide, and 10 ft. 6 in. high, and seat 52.

The car builder is a joint venture of ABB Traction/AMTRAK. ABB is a merger of ASEA (Swedish Electric) and Brown Boveri (Swiss). AMTRAK's Beech Grove, Indiana, shop will assemble the cars; the car body shell will be fabricated by SOREFAME, Lisbon, Portugal, a Budd Co. licensee. The first two shells arrived at Beech Grove in April 1989.

These cars will feature the first three-phase AC drive to be used in a production fleet for use in the United States. Each truck will be driven by its own DC–AC inverter providing variable voltage (0 to 465 volts), variable-frequency (0 to 165 Hz) power to two ASEA MJA 280–2 motors of 155-kW (208-hp) each. With four such motors, the car will have the best power-to-weight ratio of any car built to date, namely about 85 lb/hp. This compares with about 130 lb/hp for the Brill Bullet P&W cars and 136 to 140 lb/hp for the PATCO cars. The motors will be geared 5.65:1 with 28-in. wheels. Maximum motor armature speed is 5,500 rpm for the three-phase squirrel cage motor. The three-phase ac drives provide regenerative as well as dynamic braking. Disc brakes on the wheel cheeks provide friction braking for the final stop (see Figure 3).

Acceleration and deceleration are to be 3.0 mph/sec, with 0 to 70 mph to be reached in 51 sec. The high horsepower should allow the cars to maintain 70-mph track speed up the several 2.5 percent grades on the NHSL. The specification calls for a balancing speed of 80 mph and a normal, governed, running speed of 70 mph. Stopping distance is specified as 1,295 ft.

They will seat 60 persons in comfortable seats having 42-in.-wide cushions. A conscious decision was made to provide comfortable seating to attract the offpeak discretionary rider, even though this may result in 2 to 4 more peak-hour standees.

Floor heat will be provided by chopper-controlled 600-volt dc power. Lowest power will be 1 Hz (i.e., one dc pulse per second). Precise control will be possible, with resultant efficient use of power.

A roof-mounted package air conditioning unit is similar to that used on SEPTA's Kawasaki LRVs delivered in the early 1980s. It will be a sealed, ac unit powered by an auxiliary inverter under the car. Blower motors and other auxiliaries will be ac to reduce maintenance needs.

Couplers, similar to those on the Kawasaki LRVs, may be used. ASEA-designed fabricated frame bogies with chevron primary suspension will be produced in the United States. The chevrons will permit self-steering. That, plus flange lubricators, should nearly eliminate flange wear on the NHSL on which 40 percent of track is curved. These features, plus disk brakes, are expected to result in a 10-year wheel life with a 10-year truck overhaul cycle. Maintainability was integrated into the design concepts of the car specification.

The new cars will have a double-stream front door and a single-stream rear door. The latter is normally used only at terminals. The double-stream front door is provided to reduce dwell time. The suburban NHSL has zone fares, so passengers must be checked in and out. The old cars with their single-stream doors sometimes encounter excessive dwell time. With 60 versus 52 seats in the old cars, the new cars have a real need for two streams.

The new N–5 cars are expected to be as much of an advance over current cars as was the 1931 Brill Bullet over its contemporaries. They will provide a new level of speed and comfort for suburban passengers.

Maintenance Facility

It was recently decided to rehabilitate the original 1908 P&W car shop building near 69th Street Terminal, Upper Darby, Pennsylvania. A study was completed by a general engineering consultant of SEPTA's and the building was found to be basically sound, although in need of renovation. The roof and floor, in particular, need renewal. Design work will commence soon. Construction will be scheduled after the last new N–5 car is accepted.

An earlier plan called for an entirely new shop to serve both the standard-gauge, third-rail-powered NHSL and the broad-gauge (5 ft. 2¼ in.) Media-Sharon Hill light-rail trolley lines. Review of the design indicated high costs and operating problems. A study indicated that rehabilitation of existing facilities would be more cost-effective.

The proposed new shop and yard would have had overhead trolley wire for both the Media-Sharon Hill trolleys and NHSL cars because it allowed sharper curves in the yard. Underbody equipment will foul the third rail or coverboard on sharp curves. With elimination of the new car shop, it was possible to delete pantographs from the new cars. Provision for them remains in case future line extension or other needs require them.

Track Renewal

Much of the old 85-lb/yd bolted track of the NHSL has been replaced with new 115-lb/yd continuous welded rail. Concurrently, the old 75-lb/yd third rail was replaced with 150-lb/yd third rail, having curved plastic coverboard in deference to NHSL's largely unfenced right-of-way. A $5 million grant was received in early 1989 and is expected to be sufficient to replace most of the remaining mainline track.

The 69th Street Terminal area will remain to be done, with its numerous turnouts. This track is relatively recent by P&W standards, having been installed in 1963 when the present three-track terminal was built by the PST Co.

Substation Modernization

All three substations on the NHSL will have all their equipment replaced with new silicon rectifiers and associated new

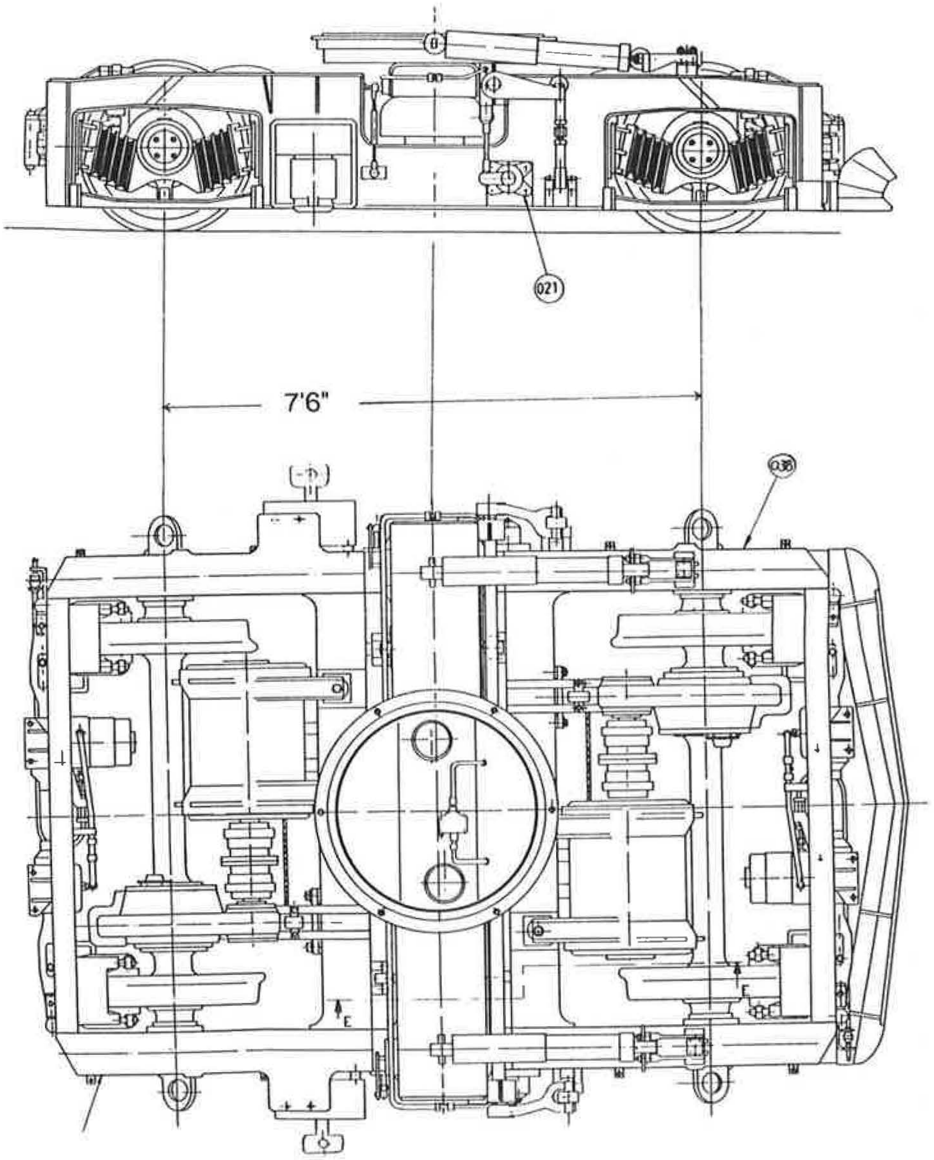


FIGURE 3 ASEA-designed car truck being fabricated by Capital Engineering & Manufacturing Co., Inc., Harvey, Ill. (source: ABB Traction).

transformers and switchgear. Old and new equipment is shown below:

Substation	*Original P&W Equipment*	*New SEPTA NHSL Equipment*
Beechwood	Three 750-kW rotaries (one later replaced with ex-Baltimore 1,000 kW)	Two 1,500-kW rectifiers
Villanova	Two 750-kW rotaries	Two 1,500-kW rectifiers
Hughes Park (originally at Bridgeport)	Two 750-kW rotaries (one later replaced by 1,000-kW rotary, ex-Omaha)	Two 1,200-kW rectifiers
Total	5,250 kW (later 5,750 kW)	8,400 kW

Output of the new substations is specified to be 630 Vdc under full load.

During reconstruction of Beechwood and Villanova in 1988 through 1991, each was replaced by a mobile 2,000-kW unit originally obtained for temporary use, while Media-Sharon Hill LRT substations were rebuilt. There is a proposal to permanently install one of these at 69th Street.

With three substations on a 13.4-mi route, the spacing is double or triple that for the typical urban rapid transit line. Yet there is sufficient power available for anticipated peak use. There is a hidden benefit in that the regenerated energy from the new cars' braking will have a relatively good chance to be received by a car in motion. With a high percentage of service to be provided by frequent one-car trains, receptivity should be reasonably good, particularly on the more densely used south end of the line.

Signal System Modernization

The project that will tie the program together will be an entirely new bidirectional cab signal and control system.

The P&W was built with conventional three-color, wayside railroad-type signals having no rapid transit-type track trips. One of the early decisions of the modernization program made in the 1970s was to install a cab-signal system with overspeed control. The accidents of 1986 substantiated the need for such a system.

The 100-Hz system used on the Northeast Corridor where SEPTA's Regional Rail Division commuter trains operate was adopted. (A similar system is used by PATCO.) The following codes have been specified:

Pulses Per Minute, 100-Hz Carrier	*Authorized Speed (mph)*
0	0
75	15
120	30
180	45
270	55
420	70

A control panel will be provided at Suburban Transit Division's Victory Avenue, Upper Darby, Control Center. It will include an indicator panel with remote control of interlockings. Two signal power supply 100-Hz motor generators will be supplied under the signal contract, one at each end of the line. All switch machines will be new—electric with hand-throw capability.

Included in the signal system and car procurement is a Vetag system to permit train operators to remotely control regularly used interlockings. This system will include both terminals as well as intermediate turn-back pocket tracks. The result is that all scheduled operations are automatic or controlled by train operators and need no intervention by a controller. The signal system was completed in late 1989 with an anticipated award date of early 1990, to be followed by about 2 years of construction. Completion is scheduled for early 1992.

A grant for $15 million was received, but it is expected that several million more may be needed. Associated and concurrent with the signal system will be an entirely new pole line the entire length of the NHSL. It is under a different design contract. The new signal and control system will bring the NHSL up to the same standards as the most modern heavy rapid transit lines.

Bridge Improvements

Bridges of the NHSL date from 1906 to 1908, when the 69th Street-Villanova segment was built, and from 1911 to 1912, when the Villanova-Norristown portion was built. All had suffered from benign neglect of a hard-pressed private owner followed by an underfunded public agency.

All bridges were inspected in recent years and were placed in three categories. Critical bridges were to receive immediate attention; priority bridges would receive attention as soon as critical bridges were attended to, and the others were placed in annual programs, 3 to 5 years in the future.

The Schuylkill River Bridge, about 3,800 ft in length, between Bridgeport and Norristown, was renovated under grants received in 1983 and 1984. Track and steel-aluminum composite third rail were included.

Three critical bridges at Mileposts 3.46, 5.19, and 7.28 are in final design and will go out for bid in 1989. Bridge 3.46 at Ardmore Junction will be completely replaced. New abutments will be built inside the old and will be tied together by an integrated roadway to provide a solid *U*-shaped structure. A multiple-girder deck will replace the old through-girder bridge over the SEPTA busway, a former PST Co. trolley right-of-way retained because the parallel public street is too narrow for safe bus operation.

Bridge 5.19 over Landover Road will be renovated. Bridge 7.28 over Aldwyn Lane at Villanova Junction will have the deck replaced, one abutment replaced, and the other renovated and repaired. That will complete the critical bridges.

Five priority bridges on the south end of the line were included in a study and design contract awarded in April 1989. The study phase was largely completed by year's end. It was determined that most can be rehabilitated.

Several road bridges over the NHSL are in poor condition, but SEPTA contends that they are the responsibility of the public agency whose road uses the bridges. Some of these are before the Public Utility Commission of Pennsylvania for a decision as to responsibility. Meanwhile, SEPTA has made emergency repairs when necessary. One such bridge, County Line Road, Bridge 8.54, was replaced by highway agencies in 1989.

The bridge program is moving ahead methodically. Four pedestrian footbridges were completely replaced under a $975,000 project during 1987 through 1989. These are at Parkview, Haverford, Bryn Mawr, and Villanova. All-new precast concrete deck girders replaced fabricated steel through-trusses that were seriously deteriorated. The only old-type footbridge remaining is Bridge 7.79 at Radnor. Its replacement is planned for 1990.

Station and Parking Improvements

Station and parking improvements are listed on the capital program but have received only about $200,000 from the operating budget for minor repairs.

Not included in the present program was modernization of the Gulph Mills parking lot as part of a highway relocation project.

69th Street Terminal Improvements

Restoration of 69th Street Terminal to its original 1906 grandeur was carried out under a $14,750,000 project that culminated in a rededication on October 27, 1988. The terminal had been designed to an excellent functional plan, so no major changes were necessary or desirable. A clutter of retail stands was removed, the skylight over the great hall was restored (it had been blacked out with paint during World War II), and lighting fixtures were restored to their original appearance. The renovation work related to the NHSL provided an expanded waiting area with improved access to buses and new electronic signs on platforms.

69th Street is served by the Media-Sharon Hill light-rail trolley lines, the NHSL, and 12 suburban transit division bus lines that all feed the Market-Frankford subway and elevated as well as three-city transit division bus lines. It is the busiest transit facility in the Philadelphia region. It may well be the only one in the United States where three suburban light-rail routes feed an urban heavy rail route. It is always busy. The project included accessibility for the handicapped.

The Norristown Transportation Center

The Norristown Transportation Center (NTC) (Figure 4) replaced the old P&W terminal with a new multimodal terminal, which includes a new NHSL elevated station, with spur, a bus loop with an enclosed waiting room at ground level, and direct access to the DeKalb Street Regional Rail Division (formerly the Reading Co.) station and its parking lot. The NTC is at Mile 13.4, whereas the old P&W terminal was at Mile 13.7. The old terminal and elevated structure beyond the NTC was demolished during the period May 17 through June 15, 1989. The NTC was occupied and in use June 16 although the spur track will not be used until the new signal system is in operation. Dedication of the NTC occurred on July 14, 1989.

The NTC is approximately an $11.7-million project integrated with the urban renewal program undertaken by Montgomery County and the Borough of Norristown.

Six Frontier Division bus routes converged on the hour (and two on the half-hour) at the curb opposite the old P&W Terminal in Norristown. These routes now use the off-street bus loop of the NTC where passengers are able to wait inside a new climate-controlled, fully enclosed building.

Bus passengers have immediate access to the NHSL by escalator and an elevator for the handicapped. The only other accessible station at the present time on the NHSL is 69th Street Terminal. Bus passengers have convenient access to the DeKalb Street Regional Rail Station by a short walkway with a pedestrian underpass under RRD tracks to the inbound platform and parking lot. The NHSL platform has a direct stairway to the expanded RRD parking lot.

The NTC is a bright, cheerful design featuring glass walls

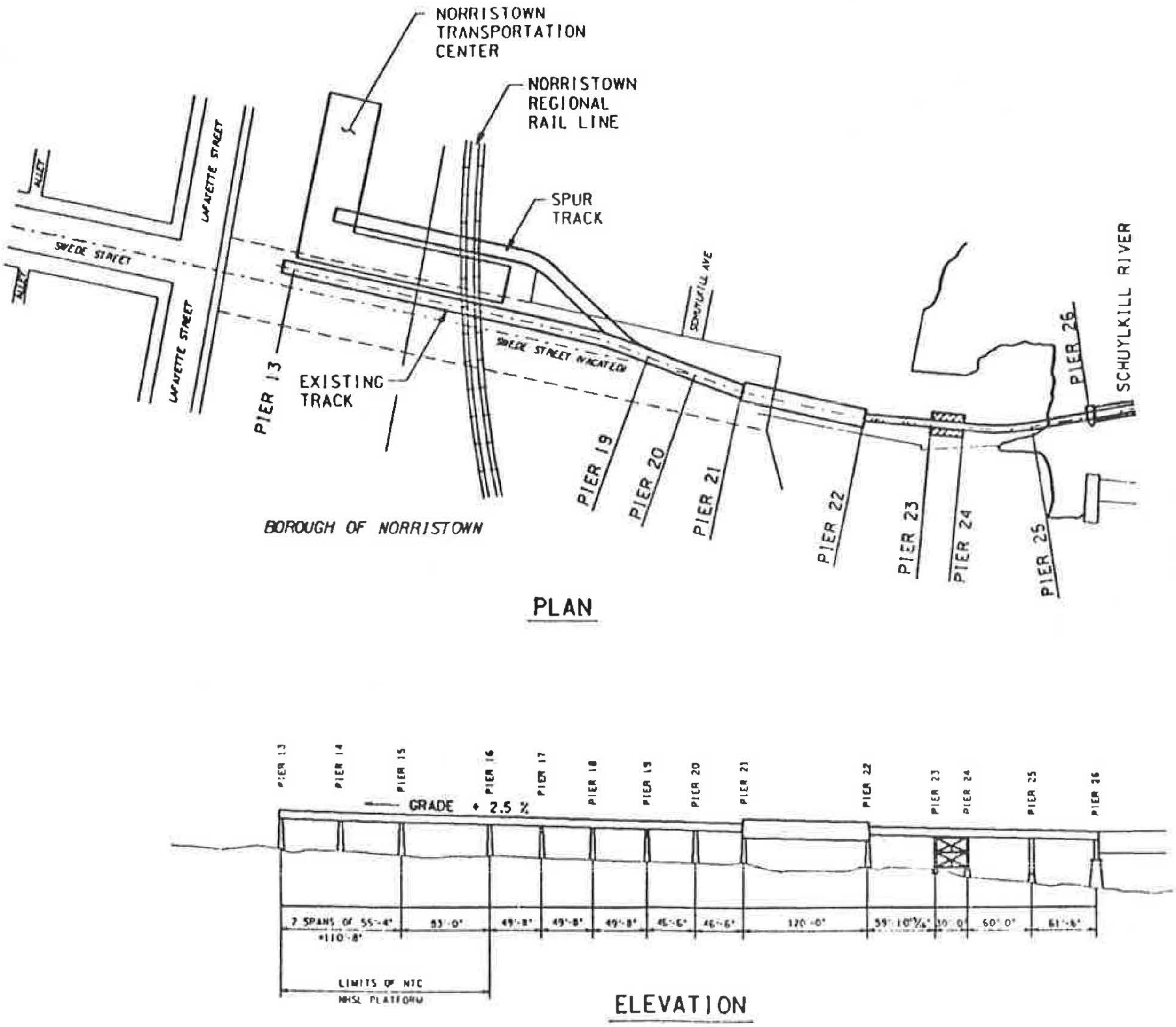


FIGURE 4 Norristown Transportation Center.

and attractive sturdy light fixtures that are suspended from the overhead canopies. Both features enhance security as well as appearance.

The NTC is an attractive and useful facility for SEPTA patrons and an asset for the urban development of the surrounding area. It is the only suburban transportation center in the United States that combines regional railroad commuter, high-speed light-rail, and bus services.

Remaining Proposed Projects

The rehabilitation and modernization of the NHSL is an ongoing program. Several projects not yet funded remain to be done. Among these are the following:

Stations and Parking. All present NHSL platforms are not long enough to accept a two-car train of new 65-ft N–5 cars. Indeed, some NHSL platforms are only a half-car long, sufficient for the front door of one car. This reflects the line's interurban railway heritage.

The SEPTA plan includes lengthening all platforms to at least 1½ car lengths so that the front door of the trailing car of a two-car train would be platformed. Selected stations would be given two-car platforms where use of all doors would be desirable.

Radnor Station may be relocated, a turn-back track built, and a new footbridge provided. Radnor Station is adjacent to a suburban employment center and is the primary destination of reverse commuters. It has excellent potential for growth.

It is desired to expand parking at selected stations where demand warrants and where land can be obtained. This is delayed until after the new cars are in operation and response of the riding public can be assessed.

Future Projects Not Yet Definitely Planned or Funded. After the new substations are in operation in 1991, one of the mobile 2,000-kW substations may be moved to the 69th Street Terminal. This procedure would ensure adequate voltage for trains ascending the 2.5 percent grade between the car shop and

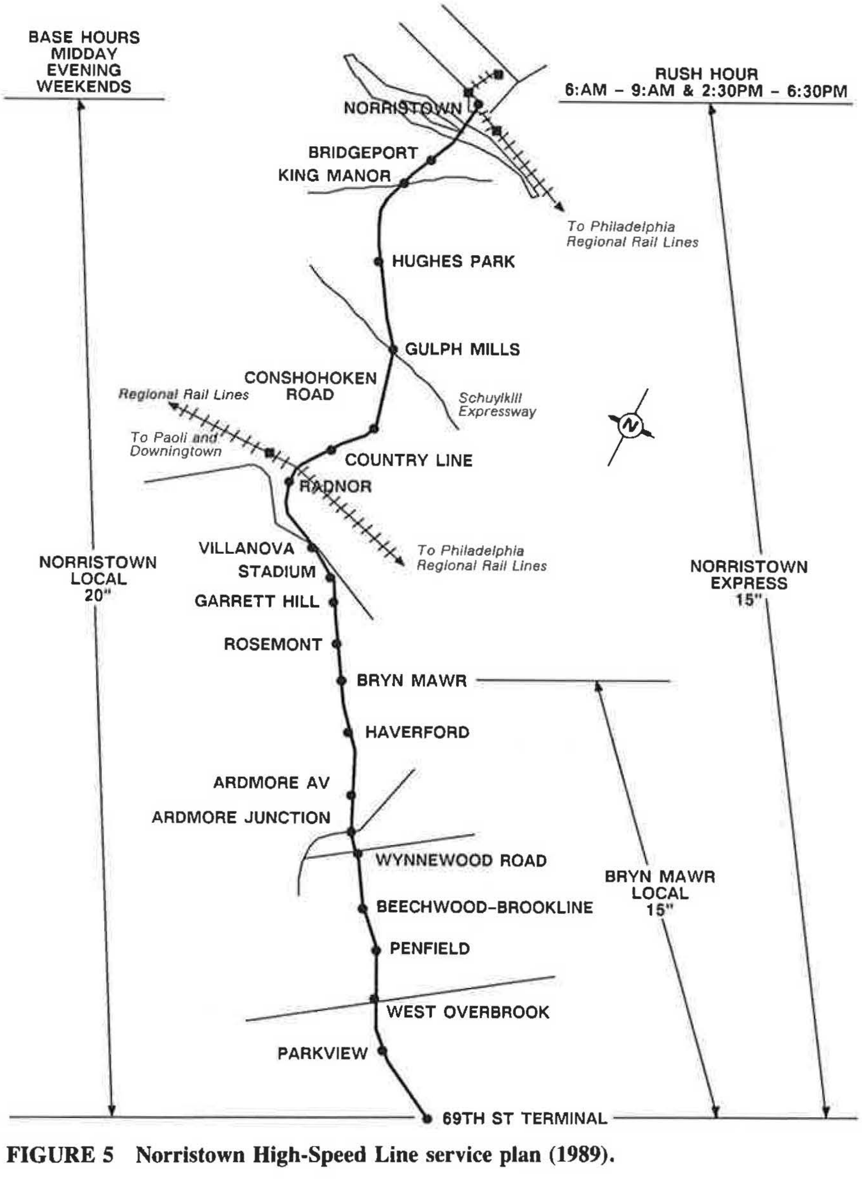


FIGURE 5 Norristown High-Speed Line service plan (1989).

Parkview-West Overbrook. It could also feed the Media-Sharon Hill light-rail trolley terminal to ensure good voltage.

King of Prussia Extension. A branch extension of about 3 mi from a junction near Hughes Park to the King of Prussia Mall and industrial center has long been considered. The PST Company had proposed a variation in the 1960s.

Such a branch might change the entire character of the NHSL because the line would then directly serve one of the largest suburban employment centers in the Delaware Valley. Sufficient new cars have been ordered to service the proposed branch.

Operating Plans. Operation of the NHSL has always been based on frequent operation of one- and two-car trains on as fast a schedule as is feasible. A line only 13.7 (now 13.4) mi with 22 stations would seem to be inherently slow, but by innovative operation, speeds have been high. All stations are unattended, and fare collection is on board.

At present, rush-hour service consists of Norristown express trains and Bryn Mawr locals. All trains stop at Ardmore Junction. Norristown trains run express, 69th Street to Bryn Mawr, then local beyond. Yet even where running local, station stops are conditional flag stops. An intending passenger must push a button to light a lunar white signal to alert the train operator to stop. A stick circuit with a timer keeps the light on until a train stops at the station and contacts an offside fourth rail to extinguish the light. An express train contacts the fourth rail too briefly to extinguish the light. This homemade P&W device is unique to the NHSL.

NHSL's rush hour is relatively long, 6:30 to 9:30 a.m. and then 2:30 to 6:30 p.m. Offpeak service is by Norristown local trains (see Figure 5).

After sufficient new cars are available and the Radnor turn back is in service, an improved operating plan (see Figure 6) will inaugurate four classes of service: Norristown Express, Radnor Express, Bryn Mawr Local, and Wynnewood Road Local. Initially, single-car trains are planned. If ridership grows as anticipated, certain services would receive two-car trains, as required.

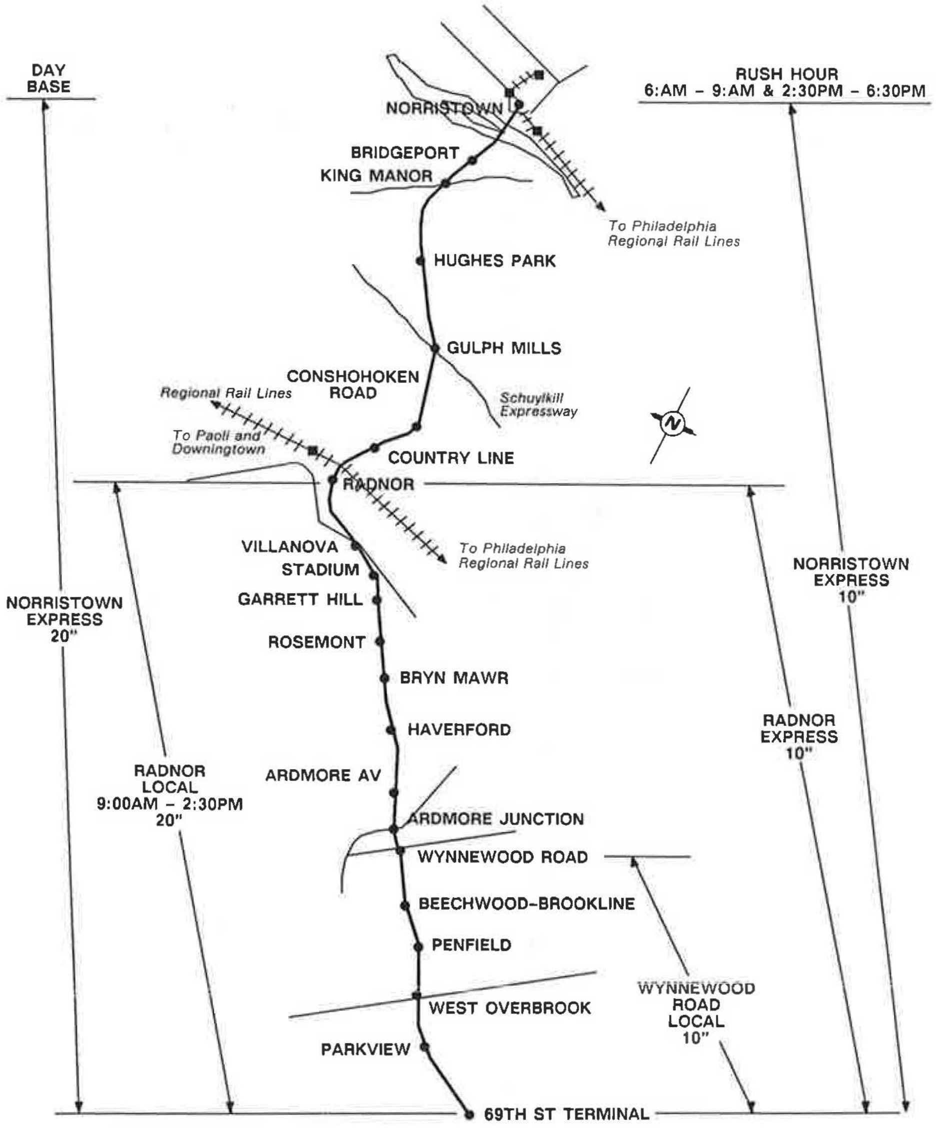


FIGURE 6 Norristown High-Speed Line—future service plan with new cars (1991).

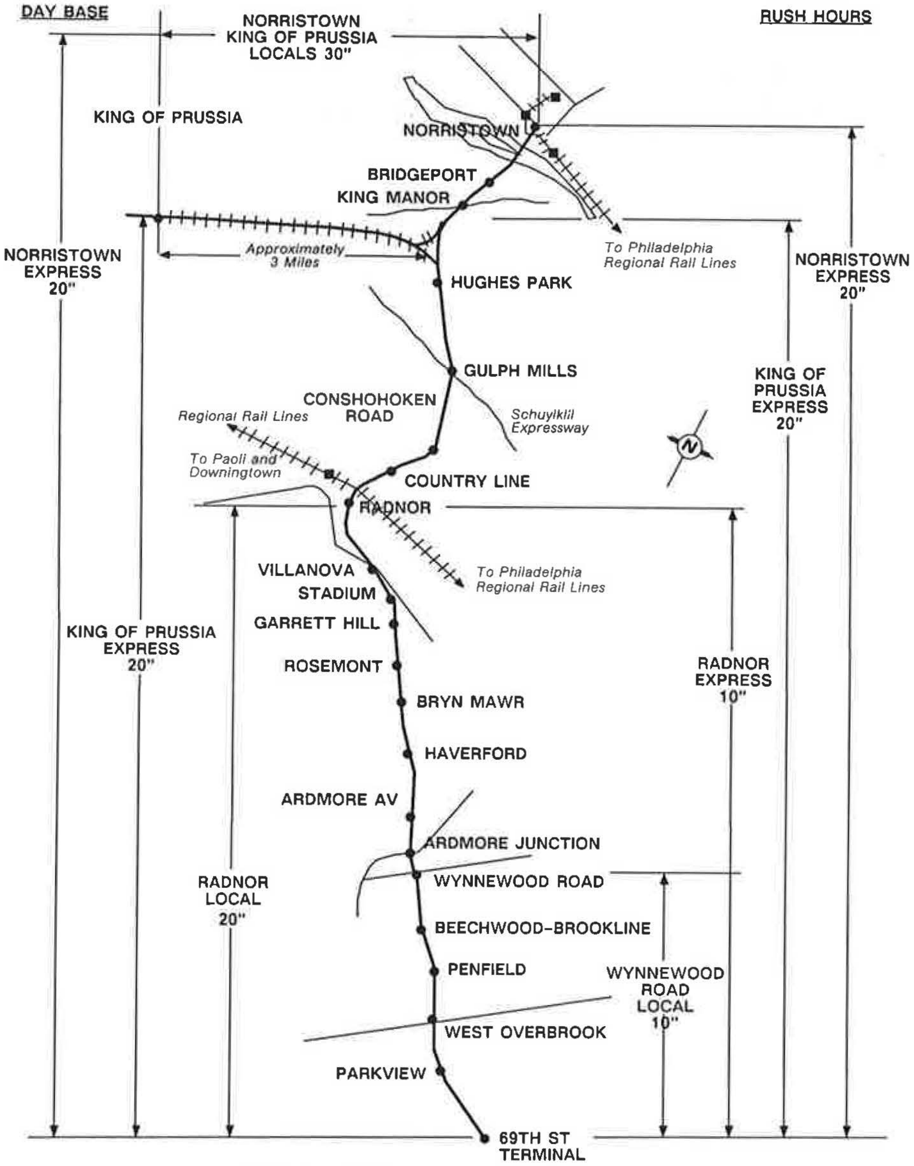


FIGURE 7 Norristown High-Speed Line with proposed branch to King of Prussia.

Should the King of Prussia branch be built, an augmented operating plan (see Figure 7) would add 69th Street to King of Prussia trains, but would also add a one-car shuttle between Norristown to King of Prussia. The latter would provide a quick connection for Frontier Division bus riders at Norristown.

CONCLUSION

The projects presently being built plus those planned for the near future will transform the NHSL into a suburban transit facility that will provide a substantially improved level of service and safety to existing and potential new NHSL patrons for the 1990s and into the next century.

The modernized NHSL provides an example that could be of use to transit agencies where abandoned or underutilized railroad rights of way may be available. Its light-rail characteristics of one- or two-car trains operating frequent service provide a higher level of service than commuter railroad at a lower operating cost and allows a lower investment than typical heavy-rail installations.

Its concept of a low-density, high-performance, high-frequency feeder to a major heavy-rail line may have application where extension of heavy-rail service into distant suburbs cannot be justified by potential patronage.

The NHSL does not fit any conventional modal definition and that, perhaps, is a definite virtue. Its existence can encourage planners to consider its unconventional yet very successful features that have served the public for over 80 years.

ACKNOWLEDGMENT

Information for this report was obtained from various internal reports and memoranda, capital budget, car specification, and signal specification of the Southeastern Pennsylvania Transportation Authority, Philadelphia, for the period 1986 to 1988. Interviews were also held with various staff members of the Southeastern Pennsylvania Transportation Authority, in particular, Ronald DeGraw, John B. Griffith, Russell E. Jackson, Howard Kohlbrenner, Raman S. Patel, and George E. Rice.

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Alternative Forms of Motive Power for Suburban Rail Rapid Transit

J. William Vigrass

Unconventional modes of rail motive power are considered. High capital costs of extending existing or new rail rapid transit lines into the more distant suburbs may have been a deterrent to implementation of some proposed extensions. Such high costs are caused, in part, by use of third-rail electrification with the perceived need for full grade separation. The longer the extension, the less the traffic on its outer extremities is a general condition that works against extension of full grade-separated rail transit into the far suburbs. Several forms of motive power are described that could offer much lower implementation costs for suburban rail rapid transit. The same concepts could apply to suburban electrified commuter railroads where electric operation is mandatory on critical center city terminal portions of a system. The proposed alternatives for heavy (i.e., high-platform) rapid transit ought to have costs on the order of those usually associated with light-rail transit, and yet would provide the spaciousness and comfort associated with suburban heavy-rail rapid transit. The unconventional motive power units described herein are intended to allow extension of existing (or proposed) electric rail transit into distant suburbs using nonelectrified railroad track that may be abandoned or used by an occasional freight train. Such existing rapid transit or commuter railroad lines are electrified because of underground operation in center cities. They generally have a roster of existing rolling stock that would have to be modified for use on nonelectrified extensions, and such modifications are described. A moderately deep discussion of technology is necessary to explain what is feasible and why. Precedent is cited in which transit trains have shared track with railroad freight trains.

The high capital cost of extending existing or new suburban rail rapid transit lines into the more distant suburbs may have been a deterrent to implementation of some proposed extensions. Such high capital costs are caused, in part, by use of third-rail electrification with the perceived need for fencing and full grade separation. In general, the longer the extension, the less traffic there is per route-mile. This is a general condition that has worked against extension of rail rapid transit into the more distant suburbs. Although there is precedent for third-rail-equipped suburban commuter electrified railroads at grade, the concept of at-grade third rail has been generally looked on unfavorably by local civic and political groups. It appears that at-grade third rail is an acceptable option only in communities where it already exists, namely in New York City's suburbs and a few locations on the Chicago rapid transit system. Where it does not exist, it is commonly perceived as being far more dangerous than the record indicates. This real institutional barrier stimulated the conceptual development of the alternatives described herein.

At the same time, suburban growth is proceeding at a rapid rate, with low-density suburbanization being the norm nationally. Several studies and papers on the subject have concluded that no form of rail transit is likely to be able to serve such areas. The potential market for transit in such areas is often below that deemed adequate for heavy-rail rapid transit using conventional criteria of population density and origin-destination desire lines. Residents of such areas do not respond in large numbers to bus transit but tend to rely on private automobiles. Typically, use of public transit in such areas is low and, in many areas, public transit does not even exist.

Numerous studies and papers have established that converging low-density suburban growth is a national and, to a lesser extent, an international phenomenon, with the result that traffic congestion within the suburban area is now common, and it is becoming worse. Means are needed to attract a significant number of motorists to public transit. It has been widely reported, and accepted, that it is extremely difficult if not impossible to attract motorists of a many-to-many trip pattern to transit.

Accepting that fact, one should also acknowledge that a still significant number of persons do commute, by driving, to centers of cities. These commuters are potential transit riders if rapid transit can be provided in low-density areas. If suburb-to-center-city motorists can be diverted from driving, the capacity they occupied can be made available to intersuburban commuting motorists. In this indirect way, transit can assist in reducing suburban congestion.

To attract suburban motorists, a high-quality rapid transit service must be provided. The Lindenwold Hi-Speed Line operated by Port Authority Transit Corporation (PATCO) is an example. It has attracted a large number of motorists to transit in an area of low population density and high car ownership. However, extension of that system has not occurred in part because the areas into which extensions had been proposed had population density too low to justify heavy-rail rapid transit using conventionally accepted measures of population density and potential transit ridership.

To provide at-grade rail transit may be possible using (a) third-rail electrification, (b) overhead catenary electric power distribution with pantograph collection, (c) a diesel-electric power car, or (d) a specially designed rapid transit locomotive (RTL) pulling modified rolling stock in conjunction with high platform stations at ground level. Such stations would be surrounded by a drainage ditch, and the rails would span such a ditch on longitudinal stringers having no cross ties. This would prevent (or at least positively discourage) unauthorized entry without payment of fare, assuming a completely controlled fare collection system. By use of the proof-of-payment (sometimes called "honor") system, simple stations without controlled access could be used the same as is done on most new light-rail systems.

Hill International, Inc., One Levitt Parkway, Willingboro, N.J. 08046.

Such an approach may permit use of existing underutilized railroad lines, specially so if time separation were ensured between railroad freight trains and transit-type trains.

There is some precedent for operation of rapid transit trains on track used by railroad freight trains. One example is provided by the South Brooklyn Railway's operation of freight trains on the Sea Beach Line of the BMT Division of the New York City Transit Authority. Absolute block operation ensures safe operation.

Another instance was operation of a freight train by Chicago Transit Authority (CTA) on the southbound express track of the north side (Howard Street) elevated line during the midnight hours when no rapid transit express trains were operating (George Krambles, unpublished data). CTA operated the service under contract with and on behalf of the Chicago, Milwaukee, St. Paul, and Pacific Railroad (the Milwaukee Road), former owner of the right-of-way. The service was discontinued in the 1960s with the decline of coal for home heating, the principal commodity handled.

The San Diego Trolley shares track with freight trains of the San Diego and Arizona Eastern Railway.

Precedent indicates that if positive separation can be maintained between passenger-carrying rapid transit trains and railroad freight trains, such operation has been permitted.

ALTERNATIVE FORMS OF MOTIVE POWER

The following concepts are for proposed extensions to existing rapid transit systems that are longer than most existing rapid transit lines and longer than some suburban electrified railroad lines. The most relevant comparison might be interurban electric railways of years past and the electrified route (third rail) of the West Jersey and Seashore (Pennsylvania Railroad) line from Camden to Atlantic City via Woodbury (1906–1949).

Alternative A

Third-rail electrification similar to that already used by most heavy rapid transit lines is suggested. This system uses direct current (dc) at 600 to 750 volts and follows general practice of nearly all existing rapid transit lines as well as two significant suburban railroad services in the New York City metropolitan area: (a) the Long Island Railroad and (b) the Hudson and Harlem lines of Metro-North Commuter Railroad (formerly New York Central).

Strictly speaking, third-rail at-grade is not an alternative form of motive power, although it is an alternative configuration for an urban heavy-rail rapid transit system that is fully grade separated. Dc allows relatively simple equipment on board the cars and is well proven and effective. Car weight is less than with alternating current (ac) distribution systems. Most importantly, any existing rapid transit car fleet would be available for use on such a route when and as required. A dc system using aluminum and steel composite third rail would need relatively fewer substations (say 50 percent) than a system using traditional steel third rail. Package substations, factory-built, are substantially less expensive than traditional substations assembled in the field by highly paid journeymen electricians. The comparative cost of a modern dc third-rail system should be relatively less than in the past.

Grade crossings require gaps in a third rail. This can be a problem for one-car trains, or even for two-car trains. Some commuter railroads use married-pair cars on which all eight third-rail shoes are connected together by a bus cable. This procedure allows the pair to span most streets that are crossed at grade. In any event, a train should coast across such a gap, to prevent arcing. This operation in turn requires careful placement of stations and signals so that a train is not required to stop on or accelerate across such a gap.

As noted previously, there is widespread opposition to at-grade, third-rail, powered rail rapid transit systems. This option, although technically preferable for some applications, might not survive public hearings.

Alternative B

A dc system using an overhead catenary is another possibility. Cleveland's Windermere-Airport Red Line uses such a catenary, as does Boston's Revere Beach Blue Line and Chicago's Skokie Swift suburban feeder. Grade crossings would be less of a problem, but maintenance costs would be higher. The West Jersey and Seashore reported that maintenance costs of its overhead were six times as much per mile as for third rail. This led to converting the Millville-Newfield Junction branch from catenary to third rail within a few years of that line's opening in 1906. Disturbances to service from fallen wires occur occasionally with catenary. It is nearly unknown for third rail to fail.

Most important, most existing rapid transit cars were not designed to carry pantographs. There is insufficient clearance between the roof of most cars and the ceiling of subways to clear a locked-down pantograph. The advantages of the present car fleet would be lost. Dc overhead is not recommended except for cases in which an all-new car fleet would be obtained that would include pantographs unless the interrelationship of the car design and subway clearances would allow installation of pantographs on existing cars.

Some existing cars might be modified to carry a pantograph (see Figure 1). This procedure would require changing the low ceiling area at the car's end where an air-conditioning evaporator is housed and may require strengthening the car's structure to carry the dead weight and dynamic load of a pantograph. This procedure may not be simple or inexpensive for a modern rapid transit car.

Alternative C

A further possibility would be a catenary delivering high-voltage ac at 25,000 volts, or 12,000 volts, single-phase, at 60 Hz. The cost per route-mile of electrification would be much less than that for a dc system. But, car equipment would be more complex, more costly, and heavier because the function of current conversion is transferred from a fixed substation to the car. A heavy transformer and rectifier are added to a car. They would not fit under most rapid transit cars. Railroad commuter cars that carry such equipment are 85 ft long and weigh about 50 to 70 tons, as compared to 30 to 45 tons for rapid transit cars.

A transformer-rectifier unit could be added to an existing rapid transit married pair by inserting a third car between the

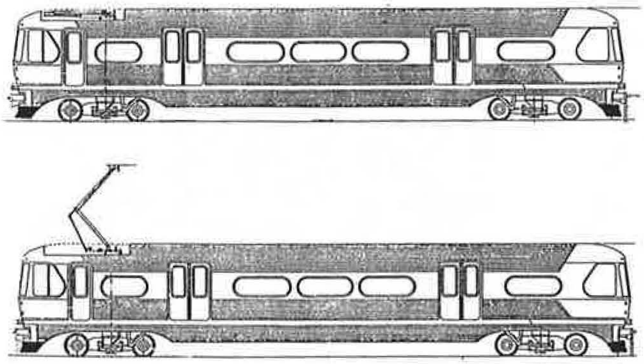

FIGURE 1 Single-unit double-ended transit car (top) with pantograph retracted and locked down for subway operation and (bottom) with pantograph extended.

two existing cars. This car would have no cab, would be semipermanently coupled to its mates, and would carry a pantograph, transformer, rectifier, and such switch gear as would be necessary to supply dc to the three-car set. The center car could be either a trailer or a blind motor car, depending on its duty cycle and propulsion equipment. Such a three-car dc/ac set would follow British Rail precedent. It is technically feasible, but a three-car passenger-carrying set would be a large minimum-sized unit for the market envisaged.

Another variant would include a short transformer-rectifier trailer and diesel-electric power car triplet. It would carry only electrical equipment and would not be a passenger-carrying car.

Overhead catenary is susceptible to damage from wind or weather far more than third rail. Occasionally, a pantograph shoe will snag a wire and pull it down with disastrous results to service.

Generally, high-voltage ac is economic when there are many track-miles versus units of motive power, as in most railroad applications. Dc systems are more economic when there are many cars per track-mile, as for rapid transit. The proposed extensions are a composite but lean heavily towards the economics of rapid transit because of the relatively large car fleet that will be available for expected peak needs.

Any type of electrification, as described in Alternatives A, B, and C may be uneconomic for the long, low-density routes envisaged as opportunities for outer suburban or interurban rail service. Only a site-specific study can indicate whether electrification is a viable option.

Alternative D

Storage batteries have been promoted by some designers for relatively long, light-density extensions of suburban railroad lines based on successful operation of about 400 battery railcars in the Federal Republic of Germany.

Those railcars are used largely on secondary intercity routes, local service, with a moderate number of stops. Most important, the amount of energy that can be stored in even a large battery that occupies all the underfloor space under a railroad-sized (80-ft) railcar is limited. The German cars can maintain a speed of only 50 to 55 mph. Batteries are expensive, heavy, and require attentive maintenance. The German cars have only two traction motors, each about the same horsepower as one of the four motors under a rapid transit car. With half the power, the rate of acceleration is low (about one-third that of a typical rapid transit car) and the top speed is two-thirds that of a modern car's 70 to 80 mph.

Battery cars would be unique and useful only on the extension. Present cars would not be usable. The one advantage, that no investment would be needed in electrification, is not sufficient to offset the disadvantages for most applications.

Battery power is not recommended.

Alternative E

Gas turbine-electric vehicles have been built in prototype form and operationally tested by the Long Island Railroad. These dual-power cars could run on third rail or from on-board gas turbines running generators. Four cars were built by General Electric Co. (GE) and four by Garrett-Airesearch Corp. The cars were operated for a short time in dual-power mode. They suffered a number of technical deficiencies (many of which probably could have been improved). They also suffered from very high consumption of jet engine fuel, a trait inherent in gas turbine engines. Fuel consumption was enormous. Operation was discontinued.

The four GE cars had their turbines removed and were converted to straight dc power. They operate with any other LIRR electric cars. The four Garrett cars were retired and sold for other uses.

The advantage of turbine power is that the heavy investment in electrification is avoided. Disadvantages are (a) larger first cost of turbine-equipped cars, (b) high operating and maintenance costs, and (c) nonavailability of the existing car fleet.

Turbine power is not recommended.

Alternative F

Diesel-electric power is another option, one that could be useful (a) as an interim measure and (b) permanently in areas where electrification would never be justified by the low potential volume of traffic.

The power car concept would be potentially useful on long extensions having infrequent stations and infrequent service.

The significant, indeed critical, advantage is that this dual-powered mode would permit through operation over the existing electrified rapid transit line and thence over any rail line extending beyond. Existing technology would be employed, using components well proven either in (a) rapid transit service or (b) railroad or industrial railcar freight switching service.

Never before has any rapid transit operator used diesel-electric railcars. It might thus be suitable for funding under UMTA's New Transit Product Introduction Program. Full 100 percent prototype funding might be available under Section 6 (R&D) plus 75/25 funding under Section 3(a)(1)(c) for a small number of introductory production units. Such a small number would probably be sufficient for an initial service.

The concept is simple. Start with an existing married pair, semipermanently coupled. Detach them. Insert between them a power car containing two 500- to 750-hp diesel-electric power plants such as those used in railroad switching, industrial, or branch line locomotives. These two engines would produce 1,000 to 1,500 hp, or 100 hp per axle for a three-car (triplet) unit. This is just enough for the continuous rating of typical traction motors. Acceleration would be less than when on third rail but adequate for service with stops far apart. The power car would look like a transit car, and windows could be simulated. Length should not exceed two-thirds of the length of a transit car. Three power cars would be as long as two passenger cars. A train of three triplets would be the same length as six transit cars, so would fit eight-car platforms (see Figure 2).

The power car would have a side corridor to allow employees and, if necessary, passengers to move from one passenger car to another. Its weight would be within the motors' and trucks' capabilities. Trucks would have steel springs rather than air springs. The power car should have an air compressor and auxiliary power converter to add to those on a married pair, providing redundancy for long-distance service. A failure 50 mi from help could be a problem. The two diesel engines provide prime mover redundancy, preferable to a single 1,200-hp engine. The two engines have an additional advantage. When idling between trips at an outer terminal, one engine alone will provide hotel power, so will conserve fuel. One would also suffice for low-speed yard movement (see Figures 3 and 4).

The power car would be a trailer having no traction motors of its own. Its only purpose would be to make electricity to power the two cars it is coupled to. The latter cars would have to have propulsion equipment adequate to haul the unmotorized, relatively heavy, power car during necessary station stops. It is envisaged that stations would be several miles apart on the type of route under consideration.

This car would be semipermanently connected to both of its passenger cars. Connectors for heavy current used for traction must be sturdy and firmly attached. It is not feasible to couple and uncouple a power car at the end of third rail as proposed by some planners. Moderate-current (400-amp) connections can be made by electrical couplers but heavy current—600 to 1,200 amps—cannot be handled reliably. Therefore, the power car must be semipermanently coupled. It was found that 1,200-amp connectors did exist, but they are manually attached, screw-type connectors made for use in oil fields. Glad-hand-type connectors commonly used to connect third-rail shoe cables to transit cars' main knife switch are contemplated as the only practical way to connect a power car's output to adjacent rapid transit cars. These are semipermanent, so they necessitate a semipermanently coupled triplet.

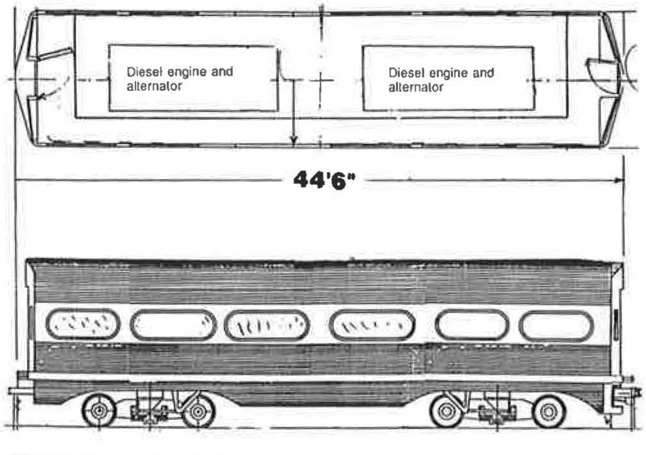

FIGURE 2 Diesel-electric power car concept.

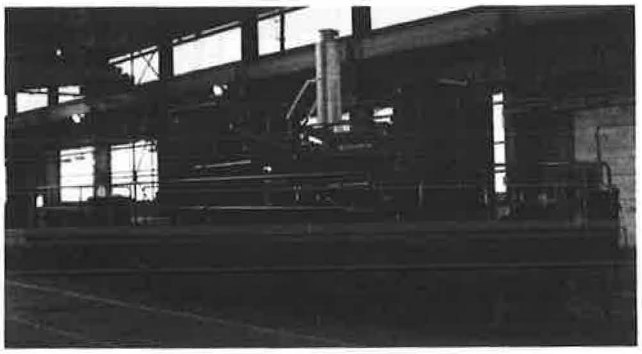

FIGURE 3 Diesel-electric power plant.

POWER PLANTS

Model No.	Cummins, KTA-1150L
Number Cylinders	6
Cylinder Arrangement	In-Line
Stroke Cycle	4
Bore	6 1/4 in. (153mm)
Stroke	6 1/4 in. (153mm)
Full Speed	2100 RPM
Idle Speed	650 RPM
Aspiration	Turbocharged/Aftercooled

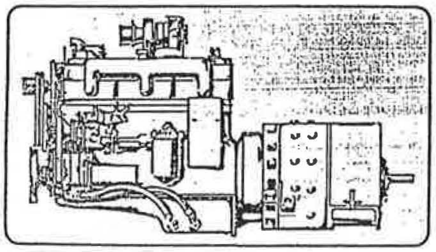

FIGURE 4 Power car would use two engines of this general type, 600 hp.

At first, an idea that seemed attractive was that of a diesel-electric power car that would be coupled to the end of a rapid transit train at the end of third rail. Power for traction and auxiliaries would be transmitted by coupler-mounted button connectors or jumper cables attached manually. It quickly became evident that this arrangement would not work because the current would be too high for any available connectors. A six-car train would need about 1,000 amps per car (at 600 Vcd). Thus, 6,000 amps would be transmitted from the power car to the first passenger-carrying car. It would be necessary to carry 5,000 amps through the first car to the second, then 4,000 amps to the next, and so forth. The cables would have to have nearly the same cross section as a third rail. Six heavy screw-type connectors requiring several minutes each to connect would be needed. This combination would be untenable.

Performance of a triplet would equal the top speed of the original existing rapid transit (or commuter railroad) cars but would have a lower rate of acceleration because of the weight of the power car and the limited output of the power car as compared with the virtually unlimited power from a third rail. For instance, in the PATCO case performance was calculated as follows:

- For a married pair, seated load, on third rail, 0 to 75 mph in 53 sec.
- For a triplet, seated load, on third rail, 0 to 75 mph in 75 sec.
- For a triplet, seated load, using diesel-electric power, 0 to 75 mph in 174 sec.

Acceleration drops markedly, but on a long line with few station stops, the lower rate should be tolerable. The rate of acceleration is about the same as for a locomotive-hauled commuter train.

A disadvantage is that the costs of operating three cars are incurred to have two carloads of passengers. This is a relatively large increase. It would be partially offset by eliminating maintenance of wayside-fixed electrical plant. However, the latter requires relatively little maintenance.

Another disadvantage is that a transit-type cab would be leading a train. This would place the train operator and possibly several passengers in a potentially vulnerable position in the event of a grade crossing collision. It may be preferable to use specifically designed cars with end construction like Long Island Railroad M-1 cars, which are designed to resist grade crossing collisions. It should be recognized that railroad passenger equipment is designed to withstand grade crossing collisions as well as collisions with other trains. The latter is reflected in an FRA requirement for 800,000-lb buff strength. The former is reflected in pilots to deflect items (such as motor vehicles) from the track as well as small end windows in cab cars (both electric multiple unit and push-pull for locomotive-propelled trains). The equipment described in this paper would operate at speeds comparable to railroad trains, namely 60 to 75 mph, so would need the same protection.

In contrast, light-rail vehicles typically operate at speeds of 25 to 45 mph in areas where grade crossings are prevalent. This is in part a reflection of the lighter vehicle with a more vulnerable end design.

Commuter rail, whether railroad or rapid transit, has a different operating environment than light rail.

The main advantage of the power car concept is the elimination of capital costs related to electrification. An additional advantage is that the power car concept probably could be implemented relatively quickly as compared to an alternative needing major civil engineering improvements.

Operationally, a triplet would be much like a rapid transit train with the addition of train-lined diesel engine control (start up, shut down, alarms, etc.). Transition from third rail to diesel-electric power could be made in motion or at a station. A passenger would not necessarily know that the change took place. The train would look like a transit train and generally would operate like one. To the passengers and the public it would be rapid transit. To the operator it would be a transit train with a one-person crew. Stations should be unattended with automatic or self-service fare collection equipment. Transit operating costs would result, rather than those of commuter railroad.

Alternative G

The locomotive-hauled rapid transit train is an innovative, perhaps improvised, alternative; yet, for several reasons it is an alternative that appears attractive for inauguration of fast, infrequent rapid-transit-type rail service.

A primary benefit of using a locomotive to haul rapid transit trains would be to have a sturdy locomotive leading the train over each grade crossing. The locomotive pilot is designed to fend off motor vehicles, and the locomotives' weight provides significant protection to the trailing cars should the train encounter a heavy motor truck on a crossing. The steeple cab design places the train operator above most impacts, and one engine or generator set is always ahead of him. This is the key reason for suggesting the use of rapid transit locomotives. Technical details follow on how this might be done.

The concept of a head-end power car that would be coupled to a rapid transit train was discarded because it is not feasible to trainline the heavy currents that would be required. Therefore, the locomotive option was considered.

Rapid transit trains would operate to the end of the third rail in the normal manner. A specially equipped rapid transit locomotive (RTL) would back from a siding and couple to the rapid transit train. This diesel-powered locomotive would be a steeple-cab, double-end unit designed for one-person operation (see Figures 4 and 5). It would have a control console similar to that in rapid transit trains. It would have the same coupler with a low-voltage (37.5-Vdc) electrical head mounted below or beside the coupler. All relevant trainlines would be usable although one, propulsion, would be commanded to coast when the locomotive is running. Other controls, such as doors, heating/ventilating/air conditioning (HVAC), lights, public address, etc., would be used in exactly the same way as when on third rail.

Auxiliary 650-Vdc power would be provided to the transit cars from the locomotive, either from its main generators or from an auxiliary generator (preferably the latter, but that would be a designer's decision), and transmitted by 650-volt bus train lines, two (or more) in parallel. On each side of the

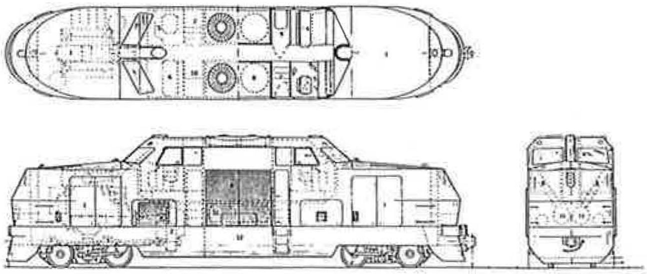

FIGURE 5 A streamlined, lightweight (50- to 80-ton) diesel-hydraulic locomotive designed for roadrailer freight service may be suitable for suburban service if equipped with a diesel-electric head end power supply.

coupler would be 650-volt, 400-amp, button connectors. The hotel load for each car is about 100 amps, maximum, so that 800-amp capacity should suffice for a six-car train and should marginally handle an eight-car train. At 650 volts, 100 amps provides 87 hp, so a six-car train would need about 525 hp just for the auxiliary load under maximum heat conditions.

A drum switch serving as a single-pole, double-throw (SPDT) switch would be energized by trainline (two trainline circuits would be needed; spares are usually provided in existing car fleets) to connect the auxiliary panel (a) to the knife switch (as at present) and thence to third-rail power, or (b) to the auxiliary 650-Vdc trainline, but never to both. The master controller in the locomotive cab would have only four power notches (P1, P2, P3, P4) rather than the eight commonly used in locomotives, but for the service intended four are enough:

P1—switching at restricted speed, 15 mph;
P2—reduced speed, about 30 mph;
P3—medium speed, 40 to 50 mph; and
P4—maximum speed, 75 mph, possibly 79 mph.

The locomotive would be wired so that the trainline wires would command coast to the trailing cars whenever the locomotive's master controller was in any power notch.

For braking, the WABCO RT5a P wire braking system or whatever is standard on that rapid transit system would be used. Dynamic braking both in the locomotive and trailing cars could be used, with friction brake for the final stop. Trainlines for those functions would be energized accordingly. Application of RT5a hardware would be designed to allow for the different braking characteristics of the locomotive versus the cars. The train operator needn't be concerned.

Only application engineering design will be needed. All components exist and are in reliable use in different places. They merely need to be brought together.

Severe brush and commutator wear might be expected on the traction motors in the transit cars when being hauled dead behind fast locomotives. However, such has not been the experience. Three examples follow.

1. The New York Central Railroad Company ran multiple-unit (MU) trains between Grand Central Terminal, Manhattan, N.Y., and Poughkeepsie, N.Y., from 1906 until about 1950 when rail diesel cars replaced the electric MUs. The MU trains ran on third-rail power to Croton-on-Hudson (a short distance north of Harmon). At that point, steam locomotives were attached, and the MU trains were towed to Poughkeepsie. The cars were equipped both with electric and steam heat. The literature does not indicate if there was severe commutator wear. The fact that the trains operated for 40 years indicates that whatever wear there was must have been tolerable.
2. New Jersey Transit Corporation towed a Jersey Arrow III MU car in Matawan-New York service for a number of weeks in 1984 with its traction motors cut out. The purpose was to investigate whether there would be abnormal commutator wear to towed cars. NJT contemplated towing MU cars on the New York and Long Branch line beyond the need of electrification at Matawan to Bay Head Junction. It was reported that no abnormal wear was observed.
3. Several railroads use fuel-saver controls on multiple-unit consists of diesel-electric locomotives by which certain trailing units are idled with their motors coasting, when their tractive effort is not needed. The extra units' power is needed and used only to accelerate the train and to ascend grades. This procedure saves stopping a heavy freight train to add or uncouple units, and so allows trains to keep moving as fast as possible (Richard C. Beck, unpublished data).

Fuel-saver units are also used in high-speed high-mileage service. It has been reported that commutator wear is worse than on motors that work all the time, and more maintenance is needed. However, the practice continues because the benefits are substantial and the problems tolerable.

Therefore, a towed transit train would probably not experience severe commutator wear, but if it should, such wear would be tolerable. The benefits from providing through rapid transit service to outer suburbs should well exceed a minor or moderate maintenance program. The practice of using the traction motors as generators in dynamic braking during those stops should keep the commutators filmed, and so less likely to their being damaged from being towed.

The primary benefit of having a locomotive haul a train would be to provide a major degree of safety to those passengers in the train and to the train operator in case of a grade crossing collision. The probability of collisions is more than zero; they will occur. The locomotive will provide substantial protection to the train, its operator, and its passengers. A second benefit is that it would not be necessary to haul a power car over third-rail territory where it would not be used. Hauling weight costs money—the added miles would increase maintenance costs. A third benefit would follow from the second in that the hazard created by hauling diesel fuel (or any other fuel) into a subway would be avoided.

The track layout at each terminal would have to provide run-around capability for the locomotives, but this would be a small price to pay for greatly enhanced safety.

The use of a locomotive ahead of a train composed of rapid transit cars not designed to withstand grade crossing collisions appears to be one means of protecting such cars.

The use of RTLs to haul rapid transit trains appears feasible.

RTL DESIGN

Sizing the RTLs should take into consideration both peak and offpeak traffic. If the locomotive were large enough to haul a six-car train, it would be much larger and heavier than needed for a two-car train. Traffic forecasts usually indicate that much of the time traffic will be light, and easily handled by a two-car 160-seat pair of cars. Yet, at peak periods, six- or eight-car trains may be needed. Therefore, it is suggested that RTLs be sized to efficiently haul a two-car train and adequately handle three cars, and that the RTLs be capable of MU operation by which two coupled RTLs could adequately handle a six-car train. One RTL and two cars (or two RTLs and six cars) should accelerate at 1.0 mph/sec. It is desirable that two RTLs be able to handle an eight-car train at a reduced rate of acceleration. Such trains, if needed, could run express. In all cases, a one-person locomotive crew should be sufficient.

The steeple-cab locomotive concept has traditionally been used in low-speed yard and branchline service. The main generator, traction motors, gearing, and truck design were intended to translate horsepower into high tractive effort at low speeds (in the range of 10 to 12 mph). The GE 144-ton, 1,200-hp unit is designed to be heavy to attain adhesion for high tractive effort (see Figure 4).

In contrast, the RTL would be designed for high speed and low tractive effort. Trucks for fast-freight (85-mph) locomotives might be appropriate, or those from four-axle passenger locomotives. The main generator (or alternator-rectifier), traction motors, and gearing would be designed for fast acceleration of a light load (three cars of 45 tons each) to 75 or 79 mph. The locomotive should be as light as possible consistent with safety requirements. About 700 hp is needed per car (600 hp for traction plus 100 hp for auxiliaries), plus perhaps 700 hp to propel the RTL itself. Therefore, an RTL might need 2,100 hp. Two engine-generator (alternator-rectifier) sets of 1,000 to 1,200 hp each appear necessary. This is a size commonly used in switching locomotives. Railroad traction motors are generally in the range of 750 hp, so that four such motors could absorb 3,000 hp. Such motors should, therefore, perform very reliably at the 2,100 hp indicated for the RTL.

The cab and hoods of the RTL could be streamlined sufficiently to ensure that wind resistance is tolerable (see Figure 5).

Design will entail significant effort for the RTL concept because it will be a new application. The fleet of RTLs will have to absorb all the design costs because no other applications for the manufacturer are apparent. A small fleet would have a relatively high design cost per unit. That should be kept in mind when deciding how many RTLs should be obtained.

Modifying existing railroad general-purpose-type locomotives as RTLs may be possible. These locomotives would probably be heavier than a purpose-built RTL, but their costs and availability might be low enough to justify their use.

Modification to a significant part of an existing car fleet would be needed, adding new draft gear, the coupler contacts, changeover switch, and two 4/0 trainline cables. Perhaps $100,000 per car might be required.

The budget for rolling stock might be roughly estimated as follows for a typical initial installation:

Item	*Amount*
Six RTLs @ $2 million	$12,000,000
Design of RTL	1,000,000
Forty cars, modification @ $100,000	4,000,000
Budget for rolling stock	$17,000,000

It may be desirable to permit use of remanufactured components such as trucks and traction motors with the dual objectives of faster delivery time and lower price.

The budget illustrates a dilemma, in that third-rail, single-track electrification could cost in the neighborhood of $30 to $40 million for a 40-mi route, sufficient for half-hourly service with no need to modify rolling stock or obtain RTLs.

Use of RTLs should not affect a transit line's status as a nonrailroad because it would still not be part of the general railroad system of the United States. The transit line would remain exempt from the regulations of a railroad.

The buff strength of most rapid transit cars used in the United States is 200,000 lb, whereas recent railroad passenger cars are built to 800,000 lb buff strength. It is undesirable and probably not permitted under FRA regulations to operate only transit-strength trains on trackage shared with railroad trains.

However, there are many railroad lines that have one freight train per day or two or three per week. Such lines may be useful for transit service if the track were time shared in a manner that provided exclusive occupancy by the freight train for a certain time period each day or week.

Usual rapid transit draft gear is not designed for the train to be pulled. Draft gear of cars to be pulled by RTLs should have been designed for that purpose. Fully automatic couplers operated from the cab would be used to permit rapid coupling or uncoupling. These are commonly used for rapid transit and are used on some electric MU commuter railroad equipment.

RECOMMENDATION

It is recommended that RTLs be given consideration as one means of extending rapid transit service to outer suburbs or nearby cities. This proposal should be compared with railroad commuter trains and single-track electrified rapid transit lines and the costs and benefits of each alternative should be compared.

REFERENCE

1. D. R. Phelps. Feasibility Study: Diesel-Electric Power Cars for Possible PATCO Atlantic City Service. In *Transit and Railroad Products Application Engineer.* General Electric Co., Erie, Pa., 1981.

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PART 6

New Technology

Planning a New Vehicle and Roadway System for Developing Countries

SHUI-YING WONG

Mechanized vehicles are needed in developing countries, because even though mass transit may be the most important means of transportation, mass transit cannot reach everywhere. The automobile is not affordable—the average price of an automobile is 30 times and its annual operating cost is 4 times the annual average wage of the workers in Shanghai, China. A new vehicle should be developed. Using socioeconomic data from San Francisco and Shanghai, a new vehicle was planned with the following attributes: a top speed of 22 mph would provide a similar capability for going to work, shopping, and visiting friends as the automobile does in San Francisco; a two-passenger vehicle with an optional two-seat compartment would satisfy most trip purposes; vehicle dimensions of 3.6 ft long, 3.0 ft wide, and 4.7 ft high would minimize investment and be technologically feasible to build. A price of $874 would be affordable to the general public. To produce such a vehicle at such a price is possible. The new vehicle, being small, cheap, requiring little space to park, can be specialized in neighborhood access and connection to mass transit. It enables mass transit to be specialized in line-haul services—concentrated on major routes with fewer stops. As a result, mass transit services would be more frequent and faster. A spoke and hub system could be developed. The spokes represent extensive local roads for the vehicle. The hubs are mass transit stations with frequent and fast buses or trains running through them. The vehicle together with mass transit would form an efficient transportation system.

The automobile is the most common vehicle in developed countries. Although there are automobiles in developing countries, they are for the rich and do not represent a viable means of transportation for the general public. To be a viable means of transportation, the use of the highway system also has to be considered. The highway system in the United States, which was developed decades ago, has reached maturity. It can be served as a maximum extent of development for future systems. To build a system similar to that of the United States would require huge investment that may not be affordable. A logical decision would be to develop mass transit. However, no matter how good mass transit might be, it cannot reach everywhere. A mechanized vehicle would still be desirable.

An appropriate vehicle and its roadway system can be explored. In order to illustrate, San Francisco and Shanghai, China, are used as example cases. In the following, what Shanghai would be like if it attained the level of automobilization as in San Francisco is described. Planning a new vehicle with respect to speed, size, power, weight, shape, and price is then discussed. Finally, the characteristics of a new vehicle and roadway system are sketched.

All data are assumed to be in base year 1987 unless stated otherwise.

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IF SHANGHAI ATTAINED COMPARABLE AUTOMOBILIZATION AS SAN FRANCISCO

What would Shanghai be like if it attained comparable automobilization as in San Francisco? The following sections describe this possibility in relation to vehicle, roadway, operating and maintenance requirements, and costs. Table 1 presents some of the data used to compare San Francisco and Shanghai.

Vehicle Requirement

In order to attain comparable automobilization, Shanghai would have similar automobile ownership as San Francisco (2.3 persons per vehicle). In Shanghai this rate would amount to 3,260,870 automobiles, representing a 12,300 percent increase from the present 26,236 automobiles (*7*). The average price of an automobile of $13,000 (*10*) in San Francisco would correspond to an expenditure of $42.1 billion in Shanghai.

Roadway Requirement

Because automobiles are parked most of the time, parking space is an important issue. San Francisco has 227,200 on-street parking spaces (*4*) that can hold 71 percent of its automobiles. To provide similar parking spaces, Shanghai would require 9,210 mi of roads (using 42 ft of curb per parking space, see Table 1). This amount represents a 1,070 percent increase from its present 786 mi of roads (*9*).

Capacity is another important roadway issue. Assuming all vehicles maintain a 2-sec headway, San Francisco's roadway capacity for different speeds would be as presented in Table 2. For instance, if the speed was 20 mph, the roadways of San Francisco would be able to accommodate 60 percent of its automobiles. To have similar capacity, Shanghai would require 9,080 mi of roads (assuming 2.4 lanes per road, as in San Francisco). This represents a 1,060 percent increase.

Table 3 presents the construction cost for new roads. Using $840,000 per lane-mi as the construction cost, the 1,070 percent increase in roadways would amount to $18.6 billion.

Operating and Maintenance Requirements

The national average operating cost for a compact car in 1984 was 17.3 cents/mi (*13*). The national average annual mileage per passenger vehicle was 9,625 mi in 1986 (*14*). Assuming

TABLE 1 DATA FOR SAN FRANCISCO AND SHANGHAI

	SAN FRANCISCO	SHANGHAI
POPULATION	742,700 (*1*)	7,500,000 (*6*)
AREA, SQ MILES	45 (*1*)	107 (*6*)
TOTAL NUMBER OF MOTOR VEHICLES	430,097 (*2*)	130,104 (*7*)
PASSENGER AUTOMOBILES	318,834	26,236
TRUCKS AND BUSES	70,087	66,728
MOTORCYCLES	17,400	18,110
OTHERS	23,776	19,030
NUMBER OF BICYCLES	NA	3,687,700 (*8*)
MILES OF ROADS	893 (*1*)	786 (*9*)
TOTAL ROADWAY AREAS, SQ MILES	7.6 (*3*)	5.0 (*9*)
ON-STREET PARKING		
NUMBER OF SPACES	227,200 (*4*)	NA
AVERAGE CURB LENGTH PER SPACE, FT.	42[a]	NA
LANE MILES	2,140 (*5*)	NA
NUMBER OF LANES PER ROAD	2.4 (*5*)	NA
POPULATION DENSITIES, PERSONS/SQ. MI.	16,500	70,400
AUTO OWNERSHIP, PERSONS PER AUTO	2.3	285.9

NA - Not available

a - (893 x 2)miles/227200

TABLE 2 SAN FRANCISCO'S ROADWAY CAPACITY

SPEED (MPH)	SPACING (FT)	% OF AUTOMOBILES ROADWAY COULD HOLD[a]
10	29	121%
20	59	60%
30	88	40%
40	117	30%
50	147	24%
60	176	20%

a - (2140 lane miles/spacing in feet)/(318834 automobiles)

TABLE 3 CONSTRUCTION COSTS FOR NEW ARTERIALS

	POPULATION GROUPS	
LOCATION	500,000 - 1,000,000	OVER 1,000,000
CBD	1.18	1.43
FRINGE	0.92	1.18
RESIDENTIAL	0.84	0.98

Notes:
1. Costs in million dollars per lane mile, including periodic resurfacing.
2. Costs projected from 1976 dollar value (*11*) to 1987 dollar value using composite construction cost indices of 58.9 and 115.6 for 1976 and 1987 respectively (*12*).

these figures were also true for San Francisco in 1987, the annual operating cost per vehicle would be $1,665. Table 4 presents the maintenance expenditure for street and road purposes in San Francisco (*15*). From 1981 to 1987, San Francisco spent $12 million (in 1987 dollars) per year to maintain its roadways. Shanghai would have to spend a similar amount or more.

TABLE 4 SAN FRANCISCO'S MAINTENANCE EXPENDITURE FOR STREET AND ROAD PURPOSES (*15*)

FISCAL YEAR	MAINTENANCE EXPENDITURE[a] ($)
1985 - 86	14,050,339
1984 - 85	11,462,199
1983 - 84	9,156,522
1982 - 83	8,383,842
1981 - 82	8,394,919
1980 - 81	6,992,199

AVERAGE PER YEAR: $11,926,656 (1987 VALUE)[b]

a - Includes patching, overlay, scaling, street lights, traffic signals, and other street purposes maintenance.

b - By converting the expenditure of each year into the present worth in 1987, using an interest rate of 4% per year.

Affordability

The average price of $13,000 and the average annual operating cost of $1,665 for an automobile were about 68 and 9 percent, respectively, of the per capita annual income of San Francisco (*16*). The average wage per worker in Shanghai was 437 U.S. dollars (*17,18*). Thus, the average price of an automobile was 30 times and its average annual operating cost was 4 times the average annual wage of the workers in Shanghai. Even though Shanghai's government would be willing to spend the $18.6 billion to build the roadways, the people would not be able to buy or operate automobiles. A new vehicle system should be developed.

PLANNING THE NEW VEHICLE

Because a developing country has limited resources, in planning a new vehicle the following objectives must be established:

- The vehicle must provide basic mobility needs,
- It must be affordable by the general public, and
- Although the vehicle needs roadways to function effectively, the investment in roadways should be minimized.

In the following paragraphs, some of the design parameters (speed, size, power, weight, shape, and price) are explored with respect to these objectives.

Vehicle Speed

Basic mobility needs include going to work, visiting friends, and shopping. The mean travel time to work for San Franciscans who live in and work within San Francisco was 24.4 min (*19*). Assuming an average distance of 5 mi (the north-south and east-west cross town distances in San Francisco are 8 and 7 mi, respectively), the average speed for going to work in San Francisco would be 12 mph. This value of 12 mph may serve as the desirable vehicle speed for going to work in Shanghai.

The ability to visit friends or to shop is in general directly proportional to the number of people that are reachable. The area covered by possible trips is

$$2DW + \pi W^2/2 \qquad (1)$$

where

D = distance traveled by vehicle, and
W = walking distance (see Figure 1).

The number of people that can be reached is

$$(2DW + \pi W^2/2)P$$

or

$$[2V_vT_vV_wT_w + \pi(V_wT_w)^2/2]P \qquad (2)$$

where

V_v = vehicle speed,
T_v = travel time by vehicle,
V_w = walking speed,
T_w = walking time, and
P = population density.

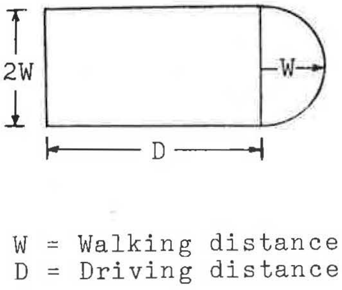


FIGURE 1 Area covered by a trip.

Given the population density in San Francisco of 16,500 persons per square mile, assuming a combined freeway-arterial speed of 45 mph and a walking speed of 4 ft/sec, a 60-min trip (including a 5-min walk) will reach 311,000 persons; a 10-min trip will reach 29,500 persons. Given the population density of 70,400 persons per square mile in Shanghai, to reach 311,000 persons in 60 min the required vehicle speed would be 11 mph. To reach 29,500 persons, the required vehicle speed would be 9 mph. Therefore, if the vehicle speed in Shanghai is 11 mph, a driver would have the same ability to visit friends or to shop as in San Francisco, because most such trips are less than 1 hr.

Although the top speed of today's automobile is about 100 mph, the a.m., p.m., and midday travel speeds in San Francisco range from 14 to 22 mph (*20*). These travel speeds may be served as a guideline for vehicle speeds.

The preceding discussions indicate that speeds ranging from 11 to 22 mph would satisfy most mobility needs in Shanghai.

Vehicle Size

The average automobile occupancy in San Francisco was 1.4 persons per vehicle (*21*). However, most automobiles were vehicles for four or more passengers. Perhaps, because the automobile is a long-term investment, people expect occasions that require the vehicle to carry four or more passengers. The effect is a waste of roadway space and energy because of moving the unused portion of the automobile.

The new vehicle should be variable in size, so that roadway space and energy can be effectively used. An approach is to design a two-passenger vehicle with an option of attaching a two-seat compartment to its rear. Figure 2 shows this concept, where *A* is the two-passenger vehicle and *B* is the attached compartment. *B* can be disconnected from *A*.

The desirable dimensions for the vehicle would be such that it could be accommodated by the existing roadway system to minimize roadway investment. To explore this, it is assumed that the new vehicle system in Shanghai would attain similar capabilities as the automobile system in San Francisco, that is, that Shanghai would reach similar vehicle ownership, parking space, and roadway capacity as those of San Francisco.

Similar ownership means Shanghai would have 3,260,870 vehicles. Assuming the 786 mi of roads in Shanghai (*9*) are linearly continuous and vehicles are parked on both sides of the roads, to park 71 percent of the vehicles, the maximum length of the vehicles would be 3.6 ft. Similar roadway capac-

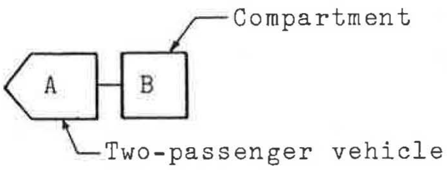


FIGURE 2 Vehicle design concept.

ity means Shanghai's roadways would be able to hold 60 percent of its vehicles during commute hours. Assuming a headway of 2 sec and an average commute speed of 10 mph (the average commute speed in Beijing, China, is about 10 mph (*22*); Shanghai is assumed to be the same), it would require 10,860 lane-mi. To provide 10,860 lane-mi, each road would have 13.8 lanes. Because the total roadway area of Shanghai equals 5 mi^2 (*9*), the average roadway width would be about 2.4 ft. Hence, the maximum vehicle width would be 2.4 ft. Therefore, if the vehicle is 3.6 ft long and 2.4 ft wide, roadway investment would be minimized.

Is it possible to have such dimensions? A 201-lb seated male requires space of 3.1 ft long, 1.6 ft wide, and 4.7 ft high (*23*). A 132-lb seated male requires space of 2.7 ft long, 1.4 ft wide, and 4.3 ft high (*23*). Assuming these two males are the design passengers, the minimum space would be 3.1 ft long, 3.0 ft wide, and 4.7 ft high if they sit side by side.

From these discussions, the size of the vehicle for two passengers would be 3.6 ft long, 3.0 ft wide, and 4.7 ft high, plus an optional 3.1 ft long, 3.0 ft wide, and 4.7 ft high two-seat compartment.

Vehicle Power, Weight, and Shape

The power of a motor vehicle can be estimated by the following equations (*24*, p. 163):

$$P = 0.0026RV \tag{3}$$

where

$R = R_a + R_c + R_g + R_i + R_r$,
$R_a = 0.0006FV^2$,
$R_g = 20WG$,
$R_i = 91.1WA$,
$R_r = 27W$,
$W = (W_c + W_p)/2{,}000$,
P = power actually used for propulsion (hp),
V = vehicle speed (mph),
R = sum of total resistance (lb),
R_a = air resistance (lb),
R_c = curve resistance (lb) = 40 lb,
R_g = grade resistance (lb),
R_i = inertial resistance (lb),
R_r = rolling resistance (lb),
F = frontal cross-sectional area (ft^2),
W = gross vehicle weight (tons),
G = gradient (percent),
A = acceleration rate (mph/sec),
W_c = vehicle curb weight (lb), and
W_p = payload, including driver, passengers and cargoes (lb).

Substituting into Equation 3, we have

$$P = 0.0026V[40 + 0.0006F(V^2) + (1/2{,}000) \cdot (W_c + W_p)(27 + 20G + 91.1A)] \tag{4}$$

On the basis of the previous discussion, the following characteristics of the design vehicle were obtained:

- Maximum speed = 22 mph,
- Payload = 333 lb (666 lb if a two-seat compartment is included), and
- Frontal area = 14.1 ft^2 (3.0 by 4.7 ft).

With the above specified, the unknowns are propulsion power, curb weight, and acceleration. Figure 3 shows the curb weight to power relationship of today's automobiles (*10*). The regression line has an R^2 value of 0.64, indicating there is a good linear relationship between curb weight and power. If we apply the power to curb weight ratio of 0.05, the curb weight of the vehicle would be 188 lb (assuming an acceleration of 2 mph/sec and the propulsion power is 60 percent of the rated horsepower). The rated horsepower would be 9 hp.

Is it possible to build a vehicle with all the attributes discussed so far (i.e., horsepower 9 hp, curb weight 188 lb, payload 333 lb, maximum speed 22 mph, dimensions 3.6 by 3.0 by 4.7 ft, acceleration 2 mph/sec, and capacity of two passengers)? What form and shape would the Shanghai vehicle be? To explore the possibilities, refer to existing vehicles.

Table 5 presents the characteristics of some automobiles. The Shanghai vehicle has less weight, power, and speed than the automobile. We may not be able to build the Shanghai vehicle with desired dimensions while maintaining the same form and shape as the automobile, because the ratio of curb weight to payload for an automobile is about 3, whereas that for the Shanghai vehicle is less than 1. Furthermore, the minimum curb weight of the automobile is about 1,500 lb, which is out of the range of the Shanghai vehicle.

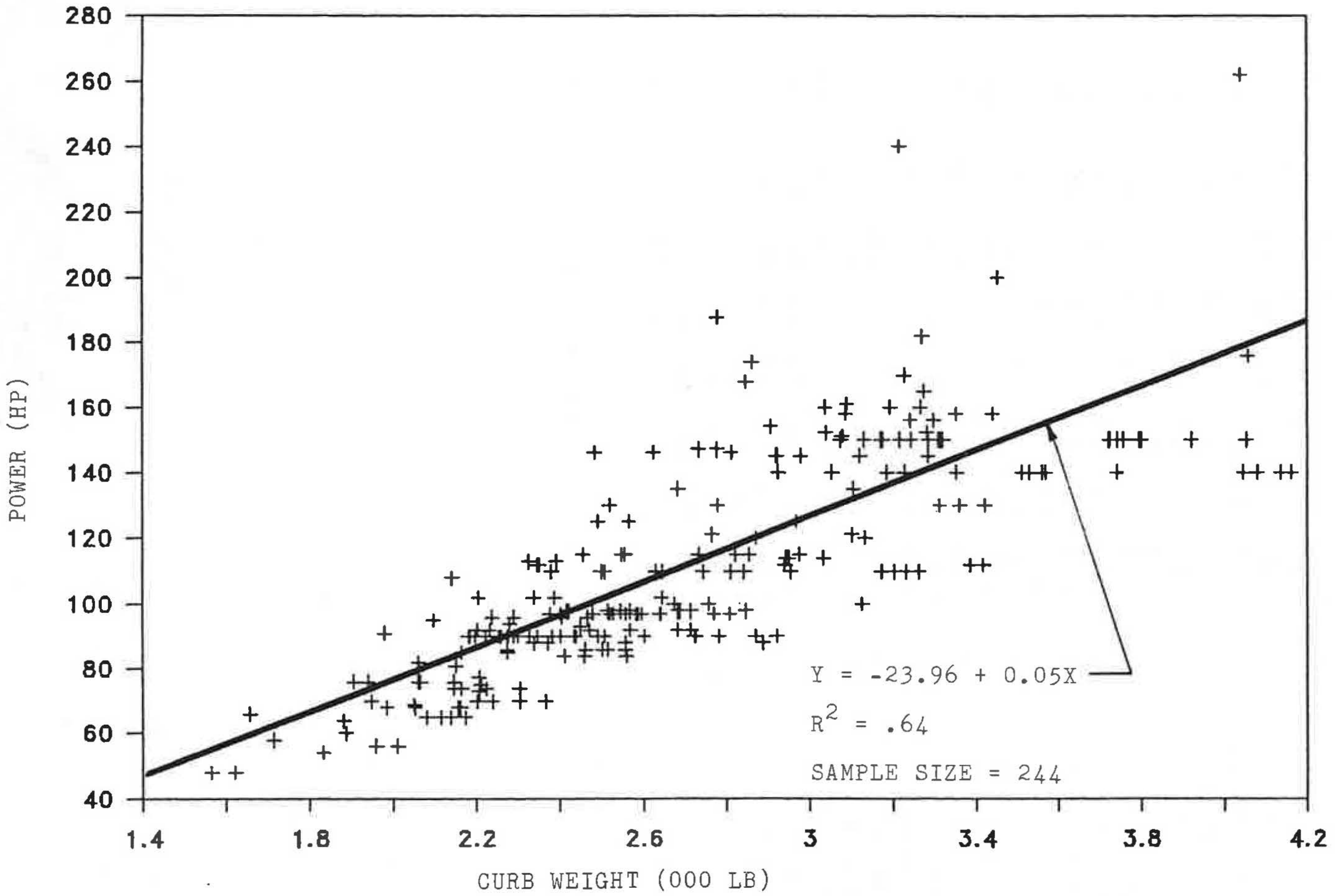
However, the shape and form of an automobile need not be maintained. Studies indicate that over 53 percent of an automobile's weight is for passenger comfort, enclosure, and safety, whereas only 47 percent of its weight is for propulsion (*26*). The Shanghai vehicle should be simple and emphasize mobility needs.

Table 6 presents data for a typical scooter with similar curb weight, payload, speed, and power as the Shanghai vehicle (*27,28*), which suggests that it is possible to build a self-propelled vehicle similar to the Shanghai vehicle. However, the scooter is not self-balanced.

Figure 4 shows a typical all-terrain vehicle. Table 7 presents its characteristics (*29*). A typical all-terrain vehicle has similar curb weight, payload, size, and probably speed and power as the Shanghai vehicle. This similarity means it is possible to build a self-balanced, self-propelled vehicle similar to the Shanghai vehicle. The all-terrain vehicle is generally not enclosed. Figure 5, however, shows how some users have added an enclosure (*30*). A similar enclosure can probably be added to the Shanghai vehicle.

Figure 6 shows some small, simple motor vehicles. Table 8 presents their characteristics (*31*). Although these vehicles are larger, heavier, and faster than the Shanghai vehicle, their ratios of curb weight to payload are similar to that of the Shanghai vehicle; therefore, it is possible to build a vehicle with the dimensions of 3.6 by 3.0 by 4.7 ft while maintaining a similar form and shape as the vehicles shown in Figures 4–6.

The above discussions indicate that we can build a vehicle with the specified attributes. Table 9 presents various power and curb weight requirements for different speeds and grades for the Shanghai vehicle.



NOTE: All 1987 model U.S. and imported passenger cars with base price less than $40,000, as listed in (10; pp. 57-59, 64-65, and 77-80)

FIGURE 3 Power and curb weight relationship of automobiles.

TABLE 5 CHARACTERISTICS OF AUTOMOBILES (*25*)

MAKE/MODEL	NUMBER OF SEATS	PRICE[a] ($)	POWER (HP)	LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	CURB WEIGHT (LB)	TOP SPEED (MPH)	ACCELERATION (MPH/SEC)
BMW 325IX	5	33,645	168	14.6	5.5	4.6	2998	126	7.7
BMW 735I	5	49,790	208	16.1	6.1	4.6	3550	143	6.6
BMW 750IL	5	69,780	300	16.5	6.1	4.6	4247	158	9.2
BMW M3	4	34,810	192	14.3	5.5	4.5	2857	141	8.7
CHEVROLET BERETTA	5	13,000	125	15.6	5.7	4.4	2804	120	7.1
CHEVROLET CAMARO IROC-Z	NA	18,083	215	16.0	6.1	4.2	3400	135	8.5
CHEVROLET CAVALIER Z24	5	13,365	125	14.5	5.5	4.3	2672	119	7.2
CHEVROLET CELEBRITY EUROS	5	17,751	125	15.7	5.8	4.5	2986	118	6.7
CHEVROLET CORSICA LT	5	13,500	125	15.3	5.7	4.7	2860	110	6.5
CHEVROLET CORVETTE	2	33,598	245	14.7	5.9	3.9	3313	154	10.7
CHRYSLER LEBARON TURBO	5	17,883	146	15.4	5.7	4.2	2920	109	6.5
CHRYSLER NEW YORKER	6	22,088	136	16.1	5.7	4.5	3319	112	5.6
CHRYSLER SHELBY CSX	5	14,160	175	14.3	5.6	4.3	2749	131	8.6
FORD ESCORT GT	NA	10,532	115	13.9	5.5	4.5	2484	109	6.3
FORD FESTIVA L	4	5,765	58	11.7	5.3	4.6	1720	95	5.9
FORD MUSTANG GT	NA	14,432	225	15.0	5.8	4.3	3300	137	9.5
FORD PROBE GT	4	17,000	145	14.8	5.7	4.3	2940	134	9.0
FORD SIERRA RS COSWORTH	5	28,500	201	14.6	5.7	4.5	2682	142	11.1
FORD TEMPO 4WD	5	12,117	94	14.7	5.7	4.4	2834	104	4.3
FORD TEMPO GLS	5	12,085	100	14.8	5.6	4.4	2721	110	5.6
FORD THUNDERBIRD TURBO	5	17,416	190	16.8	5.9	4.5	3485	131	7.1
TOYOTA CAMRY	5	12,213	115	15.2	5.6	4.5	2810	110	6.5
TOYOTA CELICA ALL-TRAC TU	4	20,000	190	14.3	5.6	4.2	3295	135	8.2
TOYOTA COROLLA	5	10,593	90	14.2	5.4	4.4	2312	103	5.3
TOYOTA COROLLA FX16	NA	10,183	108	13.3	5.4	4.4	2332	107	7.2
TOYOTA MR2	NA	15,468	115	NA	NA	NA	2466	118	6.5
TOYOTA TERCEL	5	8,028	78	13.9	5.3	4.3	2087	98	5.1

NA - Not available

a - Retail price of the vehicle, including options, as used during the vehicle road test.

TABLE 6 CHARACTERISTICS OF SCOOTERS (*27,28*)

MAKE/MODEL	RETAIL PRICE ($)	CURB WEIGHT (LB)	PAYLOAD (LB OR PERSON)	TOP SPEED (MPH)	POWER (HP)
HONDA HELIX	2,799	342	350	75	NA
HONDA ELITE 250	2,299	280	335	70	NA
HONDA ELITE 150	1,799	240	338	60	NA
HONDA ELITE 150D	1,799	232	330	60	NA
HONDA ELITE 80	1,398	172	330	45	NA
HONDA ELITE 50 LX	1,098	138	200	40	NA
HONDA ELITE 50E	899	107	180	35	NA
HONDA AERO	899	128	180	38	NA
HONDA SPREE	499	94	180	35	NA
YAMAHA RIVA RAZZ	699	115	NA	40	5
YAMAHA RIVA 200	1,999	269	(2)	75	20
YAMAHA RIVA 125	1,649	209	(2)	65	13
YAMAHA RIVA JOG	699	122	NA	35	5

NA - Not available

( ) - Number of persons

FIGURE 4 A typical all-terrain vehicle.

TABLE 7 CHARACTERISTICS OF ALL-TERRAIN VEHICLES[a]

MAKE/MODEL	RETAIL PRICE ($)	CURB WEIGHT (LB)	WHEELBASE (IN)	WIDTH (IN)	ENGINE DIS-PLACEMENT (CC)
HONDA FOURTRAX TRX125	1898	300	41.7	39.4	125
HONDA TRX200SX	2298	353	41.9	39.4	199
HONDA TRX250R	3098	340	49.8	45.7	246
HONDA TRX250X	2698	351	45.3	43.7	246
HONDA TRX300	2798	439	49.0	43.8	282
HONDA TRX300FW	3298	475	48.6	41.9	282
HONDA TRX350D 4WD	3998	590	47.6	40.9	350
KAWASAKI KLF110A2 MOJAVE	1399	264	40.9	38.4	103
KAWASAKI KLF110B2 MOJAVE 110	1499	275	40.9	38.4	103
KAWASAKI KLF185A4 BAYOU	1999	357	43.3	39.4	182
KAWASAKI KLF220A1 BAYOU	2299	399	43.9	40.0	215
KAWASAKI KLF300BI BAYOU	2749	492	47.6	43.9	290
KAWASAKI KSF250AZ MOJAVE 250	2599	372	44.3	42.9	249
KAWASAKI KXF250AZ TECATE 4	2899	328	48.2	44.5	249
POLARIS TRAIL BOSS	2227	400	49.5	43.7	244
POLARIS TRAILBOSS 2X4	2267	440	45.5	43.5	244
POLARIS TRAILBOSS 4X4	2915	490	47.5	44.5	244
RECREATIVE INDUSTRIES MAX II	3795	650	50.0	56.0	436
SUZUKI LT230SJ QUADSPORT	2488	337	44.5	41.3	229
SUZUKI LT250RJ QUADRACER	2899	325	51.2	44.7	246
SUZUKI LT300EJ QUADRUNNER	2659	450	46.2	43.7	293
SUZUKI LT500RJ	3499	392	53.1	47.4	500
SUZUKI LT80J QUADSPORT	1279	220	37.0	31.7	83
SUZUKI LTF250J QUADRUNNER	2899	495	45.3	44.1	246
SUZUKI LT-4WDJ QUADRUNNER	3499	500	45.3	44.3	246
SUZUKI QUADRUNNER	2599	379	44.9	41.7	229
YAMAHA BANSHEE	3149	375	50.4	43.3	347
YAMAHA BIG BEAR	3649	549	47.6	43.1	348
YAMAHA BLASTER	1949	313	43.3	40.7	195
YAMAHA CHAMP	1419	243	40.6	34.8	98
YAMAHA WARRIOR	2999	390	47.2	42.5	348
YAMAHA YFM 200DX	2219	386	44.1	41.1	196
YAMAHA YFM225	2599	452	46.7	43.9	223
YAMAHA YFM350ER	2899	496	46.7	43.9	349
YAMAHA YFM80	1119	213	37.2	32.5	79

a - All 1988 model all-terrain vehicles as listed in (29) except the 2-wheelers.

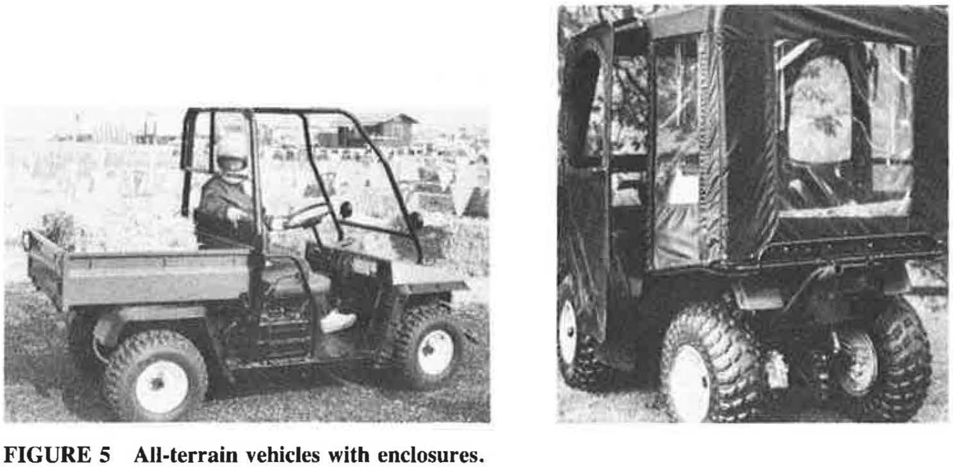


FIGURE 5 All-terrain vehicles with enclosures.

FIGURE 6 Small motor vehicles.

TABLE 8 CHARACTERISTICS OF SOME SMALL MOTOR VEHICLES (*31*)

MAKE/MODEL	TOP SPEED (MPH)	LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	CURB WEIGHT (LB)	POWER (HP)	PAYLOAD (LB + PASSENGER)
CUSHMAN HAULSTER 455	39	9.3	4.0	5.8	960	18	1,000 + 1
CUSHMAN HAULSTER 452	30	9.6	4.0	5.8	1,080	18	1,400 + 2
CUSHMAN FLATBED PICKUP 451	18	9.0	4.0	5.8	945	18	1,000 + 1
CUSHMAN FLATBED PICKUP 453	18	9.0	4.0	5.8	930	12	1,000 + 1
CUSHMAN FULLTON 450	18	10.9	4.0	5.8	1,060	18	2,000 + 1
CUSHMAN FULLTON 459	18	11.5	4.0	5.8	1,195	18	2,000 + 1
CUSHMAN MINUTE-MISER 319	14	6.8	2.9	3.2	520	7	250 + 1
CUSHMAN DELIVERY VEHICLE 456	39	9.3	4.0	5.8	1,340	18	1,000 + 1
CUSHMAN DELIVERY VEHICLE 458	29	9.8	4.0	5.8	1,475	18	1,000 + 1
CUSHMAN POLICE VEHICLE 454	39	9.3	4.0	5.8	1,165	18	1,000 + 1
CUSHMAN REFUSE VEHICLE 457	29	10.4	4.0	5.8	1,380	18	1,000 + 1

TABLE 9 SUMMARY OF DESIGN PARAMETERS FOR THE SHANGHAI VEHICLE

	LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	PAYLOAD (LB)	CURB[a] WEIGHT (LB)	PROPULSION[a] POWER (HP)	RATED[a] ENGINE POWER (HP)	ACCELERATION (MPH/SEC)	SPEED[a] (MPH)	GRADE (%)
TWO PASSENGER VEHICLE ITSELF	3.6	3.0	4.7	333	188	5.6	9.4	2	22	0
									18	5
									15	10
					251	7.5	12.6	3	22	0
									18	5
									15	10
TWO PASSENGER VEHICLE AND COMPARTMENT	6.7	3.0	4.7	666	271	8.1	13.5	2	22	0
									17	5
									14	10
					385	11.5	19.2	3	22	0
									18	5
									15	10

a - Computed from equation 10 by assuming 1) power to curb weight ratio of 0.05 and 2) 60% of engine power is available for propulsion for given frontal area, payload, acceleration and grade.

Vehicle Price

The vehicle should be affordable. In order to define an affordable automobile, refer to the experience of the United States. The automobile was available in the United States in the 1800s. However, before about 1910 it was regarded as a rich person's toy rather than a means of transportation. After 1910, the percentage of U.S. residents owning automobiles increased rapidly, as shown in Figure 7. By 1930, about one-fifth of the population owned an automobile (*32*). One reason was the automobile was mass produced and became affordable to the general public. The curves in Figure 7 show that the rapid growth of the automobile started at the time when the average wholesale price of the automobile was below the average annual family income. This fact suggests that a reasonable price during the development stage of the Shanghai vehicle should be about the same as the average annual family income. Assuming a typical family has two workers, the average annual family income in Shanghai would be $874 (*17,18*). This price would be the desirable price for the Shanghai vehicle.

Is it possible to build the vehicle for $874? Some idea can be obtained from existing vehicles.

Light pickup trucks also emphasize mobility. Figure 8 shows the price and curb weight relationship of light pickup trucks (*33*). The regression line has an R^2 value of 0.75, an intercept of 927, and a slope of 2.75. The R^2 value indicates that price is highly related to curb weight. The intercept may be related to the complexity of the production process. Today's automobile contains thousands of parts. Inventory and a well-orchestrated assembly plant are required to put these parts together. The process is complex and expensive. The setup cost for this process is about $927, as interpreted from the intercept. The price for each pound of curb weight is $2.75, as interpreted from the slope. If we apply this relation to the Shanghai design vehicle, the price would be $1,444.

Figure 9 shows the price and curb weight relationship of all-terrain vehicles. The regression line has an R^2 value of 0.67, an intercept of 287, and a slope of 5.82. The R^2 value indicates that price is highly related to curb weight. The setup price, as interpreted from the intercept, is $287. This price is less than that of the pickup truck, because the all-terrain vehicle is simpler. The cost per pound is $5.82, as interpreted from the slope. This is higher than that of the pickup truck because of economy of scale of production. Pickup trucks are produced more than are all-terrain vehicles, therefore the unit cost is less. Applied to the Shanghai vehicle, the price would be $1,381.

These facts suggest the price would be over $1,000. However, the $874 price level could be attainable because the Shanghai vehicle would be as mass produced or even more mass produced, considering the population of China, as the light pickup truck, and would be as simple as the all-terrain vehicle. If we apply the slope of the regression line of the light pickup truck (2.75) and the intercept of the regression line of the all-terrain vehicle (287) to the Shanghai design vehicle, the price would be $804.

The $874 price level could be attainable from another point of view. Table 10 indicates that the average cost of material for an automobile was about $0.33/lb. Assuming the Shanghai vehicle is made of the same materials, the material cost would be $62. The average cost of an automobile ($13,000) is 13 times its average material cost ($1,053), as interpreted from Table 10. If we apply this price to material cost relationship to the Shanghai vehicle, the vehicle price would be $806. Moreover, the labor cost in the United States is much higher than in China. The hourly wage of motor vehicles and equipment workers in the United States is $13.49 (*38*). The average hourly wage of Chinese workers is $0.21 (*17,18*), which is 64 times lower. Therefore, the production cost and hence the price would be lower.

THE NEW ROADWAY SYSTEM

At first, the vehicle would use the existing roadway system so that investment could be minimized. Research indicates that a lane width of 2.5 ft greater than the car itself is adequate (*39*). Thus, the vehicles could operate on 5.5-ft-wide roadways. The maximum vehicle speed of 22 mph is similar to that of bicycles. As a result, the existing roadways, including

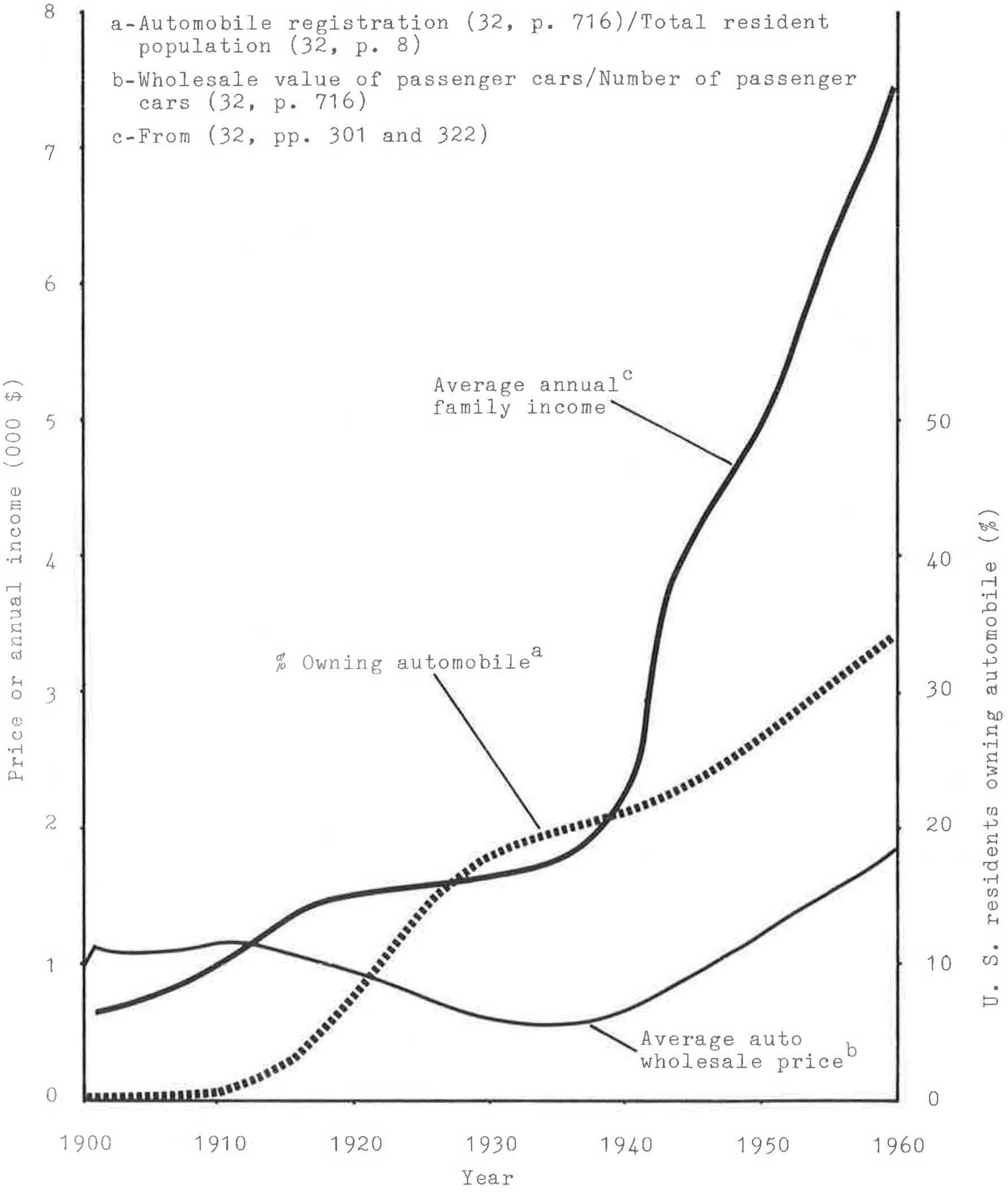
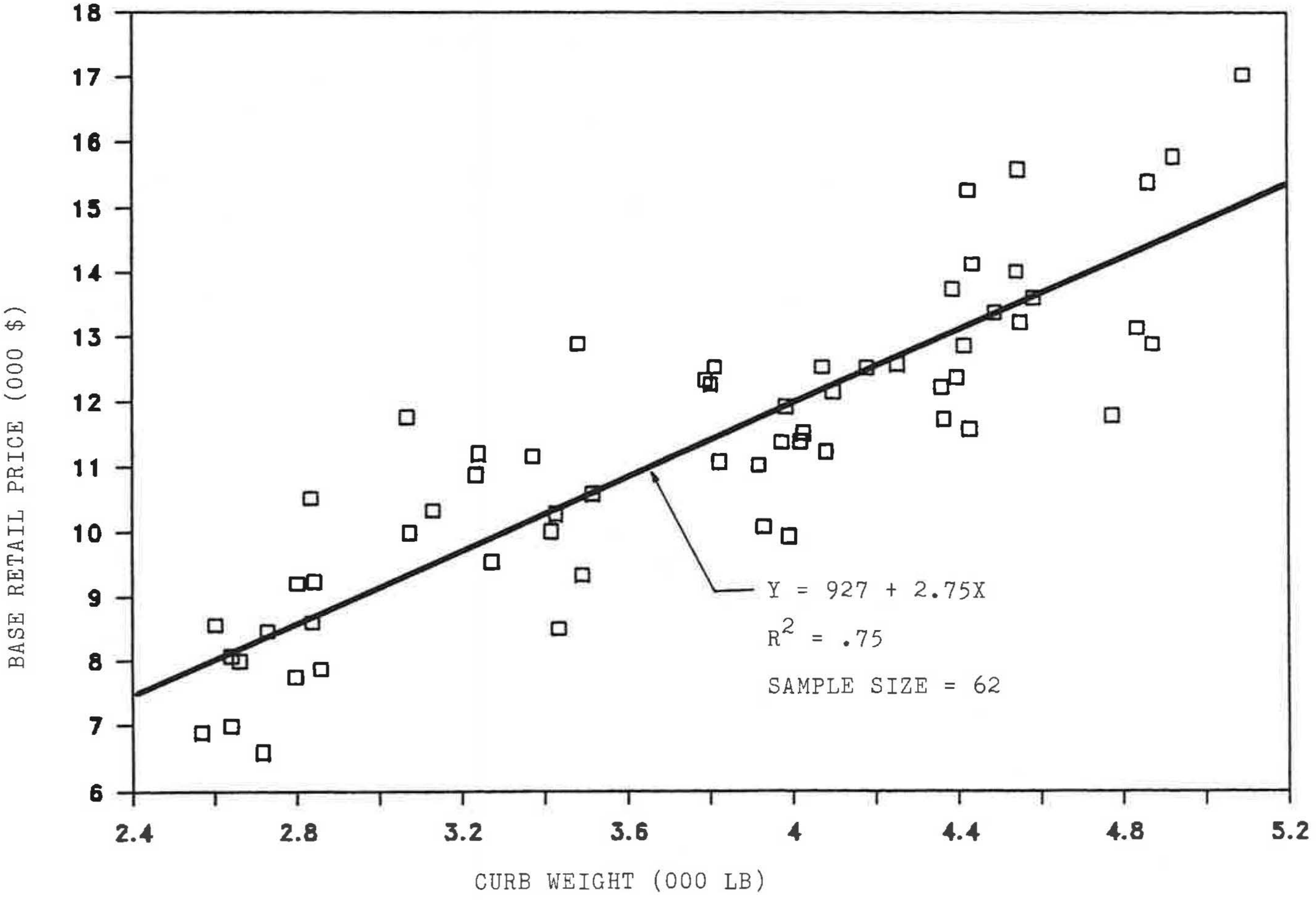
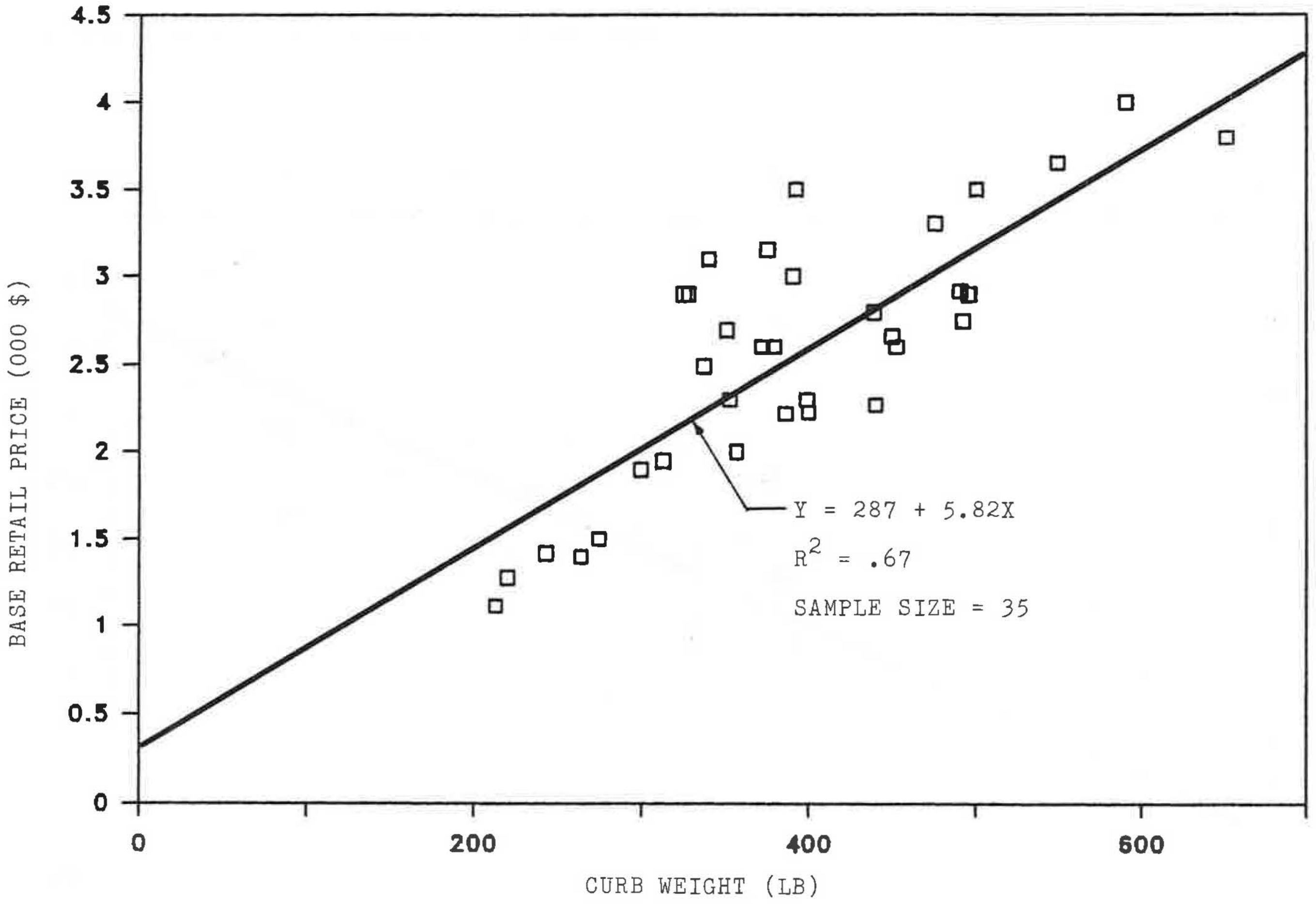


FIGURE 7 Automobile wholesale price, family income, and percent of U.S. residents owning automobiles.



NOTE: All 1987 model light pickup trucks produced in the U.S. as listed in (33, pp254-256)

FIGURE 8 Price and curb weight relationship of light pickup trucks.



NOTE: All 1988 model all-terrain vehicles as listed in (29), except the 2-wheelers.

FIGURE 9 **Price and curb weight relationship of all-terrain vehicles.**

TABLE 10 MATERIALS FOR AN AVERAGE PASSENGER CAR

MATERIAL[a]	WEIGHT[a] (LB)	(%)	UNIT PRICE[b] ($/LB)	PRICE OF MATERIAL ($)
PLAIN CARBON STEEL	1,459.0	45.9	.21	306.39
HIGH STRENGTH STEEL	228.0	7.2	.31	70.68
STAINLESS STEEL	32.0	1.0	1.49	47.68
OTHER STEELS	55.5	1.7	NA	38.85
IRON	460.0	14.5	.05	23.00
PLASTICS/COMPOSITES	221.5	7.0	.51	112.97
FLUIDS/LUBRICANTS	183.0	5.8	NA	128.10
RUBBER	135.5	4.2	.43	58.27
ALUMINUM	146.0	4.6	.70	102.20
GLASS	86.0	2.7	NA	62.20
COPPER	25.0	0.8	.68	17.00
LEAD	24.0	0.8	.29	6.96
ZINC DIE CASTINGS	18.0	0.6	.40	7.20
OTHER MATERIALS	104.5	3.3	NA	73.15
TOTAL	3,178.0	100.1	0.33[c]	1052.65

NA - Not available (assumed to be $0.7/lb, same as aluminum)

a - From (*33*, p. 30)

b - Iron and steels from (*35*), plastics/composites from (*36*), rubber from (*37*) and the rest from (*34*).

c - This is the weighted average unit price, by assuming $0.7/lb for NA items and taking the weighted average.

those designated for bicycles, could be used. Other existing facilities, such as traffic signals and service stations, could also be used.

As more and more people use the new vehicle, special systems should be considered. The vehicle, being small, can reach anywhere. It can be specialized in providing neighborhood access and connection to mass transit. Mass transit, on the other hand, can be specialized in line-haul services, concentrating on major corridors with fewer stops. Hence, transit service would be faster and more frequent without additional investment.

A spoke and hub system could be developed. The spokes represent roadways for the new vehicle. The hubs represent transit stations. Roadways connecting the hubs would be specialized for efficient buses, trains, or other mass transit services, whereas roadways for the spokes would be emphasized on local access. Park-and-ride lots and retail stores would be built at the hubs. Renting of the new vehicle and the optional compartment would also be available at the hubs. The idea is to make the hub the shopping and transportation center. People would drive the new vehicle from home to the nearest hub to get their basic needs. If they need to go farther, they would use transit to go to the further desired hub, where they could rent or lease another vehicle, if necessary, to go to their destinations. Such operation is possible because the vehicle is small, and park-and-ride lots would be easy to provide. Because the vehicle is cheap and simple to maintain, renting outlets would be easy to establish and the renting price would be cheap.

Because transit service is frequent and fast, it would be convenient to transfer from the new vehicle to transit, and from transit to the new vehicle. Developing retail stores and other activities around the hubs has great implication on shaping the travel patterns. It minimizes the need to use the new vehicle to travel long distances. It also ties the new vehicle and mass transit together. They complement each other; more use of the new vehicle would require better transit service, and better transit service would encourage more use of the new vehicle. Together they form an efficient transportation system.

Other systems could also be developed. The vehicle-train system shown in Figure 10 is an example. A person can drive the vehicle directly on board a train. The train provides efficient line-haul or intercity service, whereas the vehicle provides efficient connection from origin to the train, and from the train to the destination.

CONCLUSIONS

A new vehicle has been planned for Shanghai, China. The same rationale can be applied to any developing country. Although the new vehicle is simple and small, it would satisfy people's mobility needs. It can be connected with mass transit to form an efficient means of transportation.

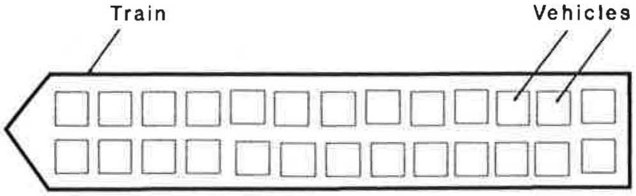


FIGURE 10 Vehicle-train system.

In China, a small farming tractor is widely used on regular roadways for transporting people and goods. This indicates there is demand for a vehicle similar to what has been described.

The Shanghai vehicle parameters were based on diesel engine technology. The reason is that because the diesel engine is a mature technology, no additional research is needed. Therefore, once the desired parameters are formulated, the vehicle can be built.

SUGGESTIONS FOR FURTHER RESEARCH

1. Because the new vehicle is small and meant to be driven at low speed and for short distances, it may be powered by an electric engine. Similar studies on developing the vehicle parameters should be based on electric engine technology. An electric vehicle, if feasible, may be more energy efficient and produce less air pollution.
2. As more people begin using the vehicle, air pollution and energy consumption become issues. Research on such impacts should be conducted.
3. The vehicle-train system is only an idea. Further research on the design of stations, logistics of vehicles getting on and off the train, arrangement of vehicles and passengers on board the train, etc., are needed before the idea becomes practical.

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Financing People Movers: The Case of Atlantic City

JOHN PUCHER, ALEX SCHWARTZ, AND CAROLE C. WALKER

A range of financing possibilities are available for a proposed people mover in Atlantic City. Unique circumstances exist there that influence the appropriateness of each technique. The financing alternatives include passenger fares, a parking tax, bus management fees, tolls on access roadways, a luxury tax, an employer payroll tax, advertising revenues, value capture, joint development, and turnkey development. Although some of these revenue sources could contribute to any financing package, the analysis shows that fare revenues would cover most capital and operating costs. This ability is due primarily to the high projected ridership that would be virtually guaranteed by a mandatory intercept of all buses and casino employee vehicles at the city periphery and a transfer of passengers to the people mover system. Fare financing would be the most practical and politically feasible financing option and would force casinos and their patrons to pay the costs of alleviating the congestion, pollution, and noise problems they have caused in Atlantic City.

A range of financing possibilities are available for a proposed people mover in Atlantic City. The analysis stems from a Rutgers University study commissioned by the New Jersey Department of Transportation in 1988 to examine the feasibility of an Automated Guideway Transit (AGT) system in Atlantic City (*1*). Following the New Jersey state referendum in 1976 approving legalized gambling in Atlantic City and the subsequent growth of the casino industry, the city experienced rapid change. By 1988, twelve casino hotels were in operation, and two of these had recently completed expansions; another is scheduled to open in 1990. Although the resulting economic growth has created new jobs and expanded Atlantic City's economic base, it has also overburdened the city's infrastructure and exacerbated environmental and social problems.

These adverse impacts have been especially severe for the city's transportation system. With 32 million visitors a year, Atlantic City attracts more tourists than any other city in the country. The ever-increasing number of automobiles and buses on city streets has exacerbated traffic congestion, roadway deterioration, and air pollution. Eighty percent of all vehicular traffic entering Atlantic City is carried by three access routes that provide six lanes inbound and six lanes outbound. Once in Atlantic City—an island city only 5 blocks wide and 48 blocks long—vehicles must traverse narrow, already congested streets to reach their casino destinations. By the late 1980s, traffic volumes had surpassed all official projections. Average traffic in the month of July soars to almost 160,000 vehicles per day. More than 1,200 buses enter Atlantic City every day, making four trips each—the first trip, to drop off passengers at the casino destination; the second trip, to a remote parking lot; the third, to go back to the casino to pick up passengers; and the fourth, to carry the passengers out of the city. In total, therefore, 4,800 casino bus trips are generated in the city every day. The opening of new casinos, the pending development of a new convention center, and the possible expansion of a regional airport all suggest that traffic congestion will increase significantly in the years ahead.

As the number of visitors and volume of traffic increased, Atlantic City commissioned transportation studies and master plans to develop ways of resolving its transportation problems. These studies recommended widening key thoroughfares, eliminating on-street parking, making additional streets one-way, and providing a computerized system for synchronizing the city traffic lights. Because of the large number of vehicles entering the city, longer-term solutions to the city's growing transportation problems were also considered. Construction of a people mover, first proposed in 1978, has often been recommended by the planning and engineering firms hired to study the problem. Although proposals concerning routes, design, and system size have varied, all have seen a people mover as integral to meeting the transportation needs of the city (*2–4*).

The Rutgers University study developed demand and cost estimates for three different route configurations. The first route, the central core configuration, consisted of a simple loop running between an intercept facility, down Missouri or Arkansas Avenue, to the three or four Boardwalk casinos clustered around Convention Hall and back to an intercept facility. The second route, the Boardwalk configuration, extended the central core configuration in a loop down the Boardwalk or Pacific Avenue to serve all of the Boardwalk casinos. The third route, the Marina-Boardwalk configuration, extended the Boardwalk configuration with a loop along Maryland Avenue to the Marina casinos. All three routes assumed a mandatory intercept of casino buses and of casino employees at an intercept facility located at the end of the Atlantic City Expressway just off the island. The financial needs of an Atlantic City people mover would obviously depend on which configuration is actually built.

Funding options available for mass transit and their application to Atlantic City are examined, taking into account the special circumstances in the city that influence the appropriateness of each technique. The advantages and disadvantages of each of the main alternatives are examined. In addition, sample calculations are made of the revenue potential of the leading alternatives. Two basic aspects of transit finance are considered: initial capital funding sources needed to under-

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write the costs of system development (guideway and station construction, vehicle procurement), and subsequent funding sources necessary to meet annual debt service and operating expenses. The final section highlights those financing alternatives that seem most appropriate, taking all of the preceding analysis into account.

GENERAL OVERVIEW OF TRANSIT FINANCE IN THE UNITED STATES

Most conventional transit systems in the United States do not pay their own way. Revenues from passenger fares are so low that they do not contribute at all to the financing of capital costs, and they cover, on average, less than half of operating costs. The remainder of operating revenue—and all of capital investment funds—are derived from government subsidies of various sorts, which amount to over $10 billion per year (*5*). Most of the capital subsidy to transit comes from the federal government, although in recent years these grants have been steadily cut back, and the prospect is for less generous assistance in the future. By far the largest portion of operating subsidies comes from state and local governments, with the federal government contributing less than a sixth of the total, and committed to reducing this percentage even further.

Conventional Financing

The state and local shares of transit financing are funded through a variety of arrangements. About half of these funds are derived from general revenues at either the state or local levels. The remainder is financed by special taxes earmarked exclusively for transit funding. Table 1 presents an overview of the types of taxes dedicated to transit funding and shows the cities and states where they are used. As can be seen, a wide range of taxes and fees are used: gasoline taxes, motor vehicle taxes, retail sales taxes, property taxes, earnings taxes, payroll taxes, parking taxes, bridge and tunnel tolls, and even lotteries. By far the most popular technique is the dedicated retail sales tax. Indeed, roughly half of the largest 20 cities in the United States earmark this tax for mass transit. An extraordinarily important earmarked source of funds in the New Jersey area is roadway tolls; in the Philadelphia and New York metropolitan areas, these toll revenues yield over $200 million in funds for mass transit each year.

Experimental/Innovative Financing

The funding techniques cited above represent the conventional means used to finance transit subsidies in the United States; they account for at least 95 percent of total state and local subsidy funding. However, support has increasingly grown for alternatives to these conventional types of funding through taxes and fees. Instead, it is argued, the private sector should increase its involvement in financing mass transit, particularly to the extent that it also profits from the increased accessibility or mobility resulting from mass transit investments. A few of these experimental financing alternatives, also presented in Table 1, are described in more detail below.

Value Capture

Value capture is not so much private financing as it is the reaping by the public sector of some portion of the profits accruing to the private sector as the result of transit improvements. Land owners and developers, for example, benefit both directly and indirectly from the proximity of their properties to new or improved transit services, especially from high-cost fixed-rail transit systems. Their properties are worth more because of direct proximity to the transit improvements. Because they are among the main beneficiaries, it is argued, they should also contribute to the financing of the system. Three types of value capture can be used to fund a portion of transit costs: special assessment districts, tax increment financing, and impact fees.

A special assessment district involves establishing the projected area of impact around the transit improvement—usually specified as within some given distance from transit stations—and then assessing a special tax on commercial properties within this area. This tax might be a surtax on the basic property tax rate, as in Miami and Los Angeles, or the levy of a special tax, such as the employer payroll tax proposed for financing a downtown people mover in Denver.

Tax increment financing, by contrast, involves neither new taxes nor higher tax rates, but rather the dedication of increased property tax revenues (that result from increased property values due largely to the transit improvement) to be used exclusively for financing a specific project. It requires the establishment of a special district around the transit improvement in which incremental tax revenues are earmarked for transit. This technique was used, for example, to finance a few of the BART rapid transit stations in San Francisco.

A third variation of value capture is the development impact fee. In contrast to other types of value capture, this is a onetime flat charge levied on new developments to finance anticipated transportation investment needs that these developments will cause. It is almost exclusively used for immediate future capital investments. The impact fee—used in Florida—often precedes the transportation investment, whereas the other two value capture options generally generate funds only subsequent to transit construction projects. However, in all types of value capture private developers are basically forced to contribute to the financing of public transportation investments.

Joint Development

Joint development requires considerably more cooperation between the private and public sectors than is generally true of value capture financing. In general, it entails coordinated development both of a transit system and of commercial facilities around it. Examples would be office towers or shopping complexes built over or near transit stations. The nature and extent of the private contribution to financing the transit investment is variable. It can involve a negotiated contribution by the private developer of land or a portion of capital costs; or the leasing of land or air rights; or the payment of special fees for access connections between the commercial project and the transit station. It also can be a genuine joint venture between the transit system and a private developer, where

TABLE 1 STATE AND LOCAL FUNDING OF MASS TRANSIT (*6–8*)

Tax/Fee/Technique	**Where Used**
Conventional Financing	
Gasoline Taxes	Florida, New Jersey, Northern Virginia, Chicago
Retail Sales Tax	Atlanta, Chicago, Houston, Dallas, Seattle, Los Angeles, San Francisco, San Diego, New Orleans, Kansas City, Denver, Cleveland
Property Tax	Miami, Minneapolis, Boston, San Francisco
Employer Payroll Tax	Portland (Oregon), Eugene (Oregon), Denver
Earnings Tax	Cincinnati
Motor Vehicle Tax	Detroit, Chicago, Seattle
Parking Taxes/Fees	Baltimore, Washington, San Francisco, New York, Pittsburgh
Bridge and Tunnel Tolls	New York, New Jersey, Philadelphia, San Francisco
Lottery	Pennsylvania, Arizona
Experimental/Innovative Financing	
Value Capture	
Special district assessments	Miami, Los Angeles, Denver, San Francisco
Property tax increment	San Francisco
Development impact fees	San Francisco, Florida
Joint Development	
Negotiated private sector investments	Dallas
Leasing land or air rights	Washington, Los Angeles, Denver
Connector fees	Washington, Miami
Joint venture development	Atlanta, Denver, Miami, Dallas-Las Colinas
Vendor Financing	New York
Turnkey Development	Houston
Private Ownership and Operation	Tampa, Las Vegas

the undertaking is truly integrated, and where both sides share in financing the up-front costs as well as the income derived from the project.

Private Ownership, Construction, and Operation

The extreme form of private involvement in transit financing is completely private ownership, construction, and operation. Private firms are responsible for raising capital, designing the projects, contracting for their construction, and managing and financing their operation. Although this alternative may sound appealing, there is a good reason why it is not used in any major transit system. Such totally private ownership and operation is possible only where it is profitable, and there are no major urban transit systems in the United States that even approach profitability. Of course, in the early 20th century, almost all transit systems were privately owned and managed, but by 1990, they are almost all public. The only totally private systems are usually small in scale or built to operate as part of larger, overall private or semipublic developments, such as amusement parks, airports, and zoos.

FINANCING SYSTEM CONSTRUCTION

Because the construction of people mover systems can cost up to several hundred million dollars, they are usually too expensive to be financed out of a state or local government's general fund. Unless most of the initial capital costs can be covered by federal subsidy, these funds are usually borrowed. The total amount of capital needed to build and equip a people mover system depends on the technology selected, length and configuration of routes, number of vehicles, frequency of service, costs of construction, and costs of land and air rights acquisition. The cost estimates for the proposed people mover in Atlantic City range from $135.6 to $529.6 million depending on the system technology and which of the three alternative route configurations is chosen. These estimates do not include land and air rights acquisition costs because Atlantic City would probably either donate air rights and rights-of-way or charge a nominal fee for their use.

Depending on whether system ownership and management are public or private, there are a variety of debt instruments and subsidies available to underwrite the costs of transit system development. Public sector, private sector, and public-private transit agencies have different if sometimes overlapping funding options. These are reviewed below.

With Public Ownership

The availability of tax-exempt debt instruments distinguishes the capital financing options of publicly owned transit systems (*9–11*). Because state and local government-issued bonds and notes are tax exempt, these bonds can be offered at a lower interest rate than would be required of otherwise equivalent taxable corporate bonds and still be marketable. States and local governments have recourse to four basic debt instruments to finance large capital projects. These include general obligation bonds, issued under the full faith and credit and taxing powers of the local government; revenue bonds backed by the net revenues generated by specific projects; special assessment bonds secured by specific levies on property benefiting from the improvements financed by the bond; and special tax bonds secured by sales taxes on specified transactions (e.g., gas, parking, hotel rooms).

General obligation bonds usually pay a lower interest rate than do revenue or special assessment bonds because they are secured by the full taxing power of the local government. Their issuance, however, is often restricted by state regulations. General obligation bonding capacity is usually limited by legislative statute to a fixed proportion of the government's property tax base. Furthermore, in some states, the issuance of general obligation bonds is subject to voter referendum.

In Atlantic City, general obligation bonds are limited to 3.5 percent of the municipality's total equalized real property valuation as averaged over the most recent 3-year period. Because Atlantic City's 1988 equalized property value was $6.6 billion, the city is subject to a total bonding limit of about $160 million, of which about $70 million is already committed to other projects. Only $90 million would be potentially available for financing a people mover. In addition, proposed general obligation bond issues must be presented for discussion at public hearings, although voter approval is not required.

Although revenue, special assessment, and special tax bonds generally require higher interest rates than general obligation bonds, they are usually exempt from debt limitations and voter approval. They can also be issued by agencies that lack taxing authority and are therefore prohibited from issuing general obligation bonds.

In addition to these three types of publicly traded debt issues, local governments may use financing techniques such as lease-purchase agreements and vendor financing. Under a lease-purchase agreement, private investors purchase equipment or property from the manufacturer or developer and lease it to the transit agency. The transit agency agrees to pay the purchase price plus interest (usually tax-free) to the investors over a specified term. Vendor financing is provided by the seller of transit equipment. In addition to the equipment, the vendor provides the transit agency with the loans, loan guarantees, or other financial arrangements that make possible the equipment purchase. When vendors provide financing in addition to equipment, however, they may be entitled to charge a higher price for the equipment than if the financing were obtained from other sources.

Not only is a variety of basic debt instruments available to finance a capital project, but these instruments can be structured an even greater number of ways. Interest rates may be fixed or variable, or a combination of the two; maturation dates can be fixed (term bonds) or variable (serial bonds). Interest payments may even be delayed until bond maturation (zero-coupon bonds). How the debt is financed will ultimately depend on such factors as prevailing interest rates, tax policies, government debt ceilings, bond ratings, and capital availability. An investment banking firm would ultimately have to be hired to determine the specific details of the optimal financing package.

In addition to—or in place of—debt financing, up-front capital funds are often obtained from federal subsidies, usually from UMTA. UMTA, in fact, financed most of the capital costs of the two people mover systems operating in major urban centers—Detroit and Miami. The Detroit people mover was funded 80 percent with UMTA grants, and the Miami Metromover was built with 75 percent UMTA funding. The Morgantown people mover, one of the nation's earliest automated guideway transit projects, was also funded largely by UMTA.

UMTA currently administers two complementary capital assistance programs for urban mass transit: the Section 9 Block Grant Program, and the Section 3 Discretionary Grant Program. Section 9 provides funding for capital, operating, and planning expenses of urban transit systems. Funds are apportioned to designated urban areas through a complex formula based on demographic variables, service levels, and ridership levels. Section 3 provides supplemental capital assistance for selected major Section 9-funded projects. For fiscal 1989, the Atlantic City urban area was apportioned $803,027 in Section 9 funds. Of this amount, over 95 percent is designated for operating and planning expenses, leaving only $35,318 available for capital assistance. Section 3 appropriations for the entire state of New Jersey in fiscal 1989 are approximately $65 million (UMTA and Atlantic City Urban Area Transportation Council, unpublished data).

Due to the extremely high costs and low ridership of the people mover systems in Detroit, Miami, and Morgantown, UMTA seems unwilling to fund additional downtown people movers (*12*). More important, the Reagan and Bush administrations have been committed to reductions in federal spending for mass transit. Almost all UMTA funds for New Jersey are presently allocated to New Jersey Transit, the main provider of transit services in the state. These funds are dedicated to financing a wide range of capital projects such as train and bus procurement and overhaul, and construction of new bus maintenance facilities. With actual capital expenditures currently totaling more than $200 million, UMTA funds now cover about half of New Jersey Transit's capital budget, and their use is largely restricted to infrastructure improvement projects (New Jersey Transit, unpublished data). Shifting UMTA funds from New Jersey Transit to an Atlantic City people mover system would require politically difficult decisions at the highest levels of state government.

Although the prospects of federal (UMTA) funding of capital or operating expenses are highly unlikely, some UMTA money could perhaps be made available on a one-time basis for start-up planning, design, and engineering work. UMTA's Entrepreneurial Service Program, a part of the administration's Private Initiatives Program, provides one-time start-up funds for privately run transit programs. Another source of UMTA seed money could be the Section 8 Technical Studies Program, a discretionary grant program for planning purposes. A total of about $1 million in Section 8 money is allocated to New Jersey each year, most of which goes to New Jersey Transit (UMTA, unpublished data).

Another potential, but even less promising, source of federal subsidy is FHWA's Federal Aid to Urban Systems (FAUS) program, which is primarily geared to highway improvement programs in urban areas. Federal guidelines permit FAUS money to be used for capital spending on transit systems instead of highway improvements, provided state and federal highway authorities approve such a reallocation. Although possible, this option is rarely used. A total of about $1 million of FAUS money is appropriated to Atlantic County each year. These are actually state funds allocated to the county under the New Jersey's FAUS swap program. In order to reduce federal oversight of local transportation projects, FAUS funds allocated to each urban area are exchanged for the same amount of state funds. The county has earmarked these funds for its Corridor Improvement Program, which matches developer contributions for new traffic signals and other road improvements (Atlantic County, New Jersey Department of Transportation, FHWA, unpublished data).

Regardless of its actual availability, it should be recalled that federal funding comes with many strings attached that affect virtually every aspect of transit design and generally inflate the cost of a transit system. Thus, even if federal funding becomes available, it may be advisable to forego such funding—as have more and more cities—to avoid costly delays reflective of federal influence over design and operating parameters. Delays and other inefficiencies caused by the need to comply with various federal design and construction guidelines, for example, are often cited as reasons for the cost overruns of the Detroit and Miami people mover systems.

Another potential capital funding source may be the New Jersey Transportation Trust Fund. Initiated in 1984 and renewed in 1987, the fund is New Jersey's principal means of financing transportation capital improvements. The trust fund is authorized by the state legislature to appropriate a maximum of $365 million annually to state, county, and local transportation projects. The funds are derived from several sources, including a gasoline tax, truck license fees, and toll road authority contributions, with the balance provided by 10-year bond issues. At present, the $365 million annual spending cap effectively limits fund appropriations to the purpose of maintaining and improving existing transportation systems, thus restricting the opportunity to fund new transportation systems such as a people mover. If, however, the state legislature permitted the $365 million annual spending cap to be lifted, or if it exempted bond issues for self-liquidating investments (such as a people mover) from the annual cap, it might become possible for the trust fund authority to issue the bonds necessary to underwrite the people mover's development. Fare box and other revenues would have to be sufficient to cover necessary debt service costs—and would have to be earmarked for this purpose. Such changes would significantly change the nature of the fund, and they would require approval from the governor and state legislature (New Jersey Transportation Trust Fund authority, New Jersey Department of Transportation, unpublished data).

With Private Ownership

Privately owned and operated transit systems are rarely eligible for federal capital subsidies, except as these are channeled through public transportation agencies. Nor are they entitled to issue low-interest, tax-exempt bonds. They do have available a variety of market-rate debt instruments, which, like state and local government bonds, can be set at a variety of maturation dates and interest rates. Besides publicly traded bonds, private firms can also obtain financing through bank loans or private placements—loans from various pension funds, insurance companies, and other financial institutions with ample capital funds to invest. Unlike public agencies, private entities also have the option of raising funds through equity (stock) offerings. In addition to common stock, these may include debentures as well as convertible secured equity. In general, private firms rely on a combination of equity and debt to finance major capital investments so as to capture potential tax savings.

With Public-Private Partnerships

When state or local government agencies combine with private companies to develop and operate a transit system, the resulting entity may have access to some of the funding options available to either sector. Through turnkey development arrangements, for example, private developers might qualify for low-interest, tax-exempt financing because system ownership would ultimately revert to the government. Access to state or municipal bond markets can lead to debt service savings of millions of dollars a year. For example, the average interest rate for seasoned AAA-rated municipal or state bonds is presently 7.56 percent, while that for similarly rated corporate bonds is 9.90 percent. At these rates, a 30-year $300 million municipal bond issue would require annual debt service costs of $26.6 million, while an otherwise identical corporate bond issue would incur annual debt service payments of $35 million, 24 percent more (*13*). Other public-private arrangements such as lease-purchase agreements may also permit low-interest financing.

FUNDING OPTIONS FOR ANNUAL DEBT SERVICE AND OPERATING COSTS

Most of the general transit funding alternatives listed earlier are also possible—at least in theory—for people movers as well. There is no reason why a people mover could not be financed with conventional dedicated taxes such as a sales tax, for example. However, most existing people mover systems have not been financed by traditional means. Most significantly, the private role in construction, operation, and financing has been much greater than for other forms of mass transit, with the exception of those systems that are in an urban context, and thus can be designated as downtown people movers—an important exception. Even the urban systems are much less regional in their impacts than conventional transit systems, so that one might expect that the usual regional-wide tax financing would be inappropriate to fund them.

Seventeen currently operating people mover systems in the United States are presented in Table 2. Only two of the systems listed—those in Detroit and Miami—operate in a truly urban context, such as that in Atlantic City. The systems in Tampa and Morgantown are in semi-urban contexts. Tampa's system is simply a short link from the city center to a private development. The Morgantown system links two campuses of the University of West Virginia, one of which is near the center city. Likewise, the Duke University system connects a parking facility with two separate buildings of the university's medical center. Seven of the other systems are for access among airport terminals; three are for transportation within amusement parks; and two are for transportation within zoos.

Fares are not usually used to fund people mover systems. As seen in Table 2, the vast majority of the existing systems charge no fares at all. In the case of airports, the costs for the people mover are considered part of the normal costs of airport operations, with the people mover viewed as a horizontal elevator. The people movers in amusement parks and zoos are financed through general admission prices, with no additional charge for use of the people mover. Likewise, the Duke University system is free. Only the systems in Detroit, Miami, Tampa, and Morgantown charge fares, and these are low: 50¢ in Detroit and Morgantown and only 25¢ in Miami and Tampa. In Miami, passengers can transfer without charge from the Metrorail system, and such free transfers account for most of the people mover's ridership.

An Atlantic City people mover would not be typical of most urban transit systems. It would include a mandatory intercept facility for casino buses and casino employees and thus enjoy a captive market. In addition, there would be a discretionary market of automobile visitors, conventioneers, and casino-to-casino visitors. Moreover, the innate tourist appeal of a people mover system might further promote ridership. Unlike the situation in other cities, fare box revenues would therefore constitute an important source of system finance in Atlantic City. The likely magnitude of fare box revenue is considered later.

People movers are usually financed through means other than fare revenues. In most cases, such as in airports, amusement parks, and zoos, the costs are financed as part of the overall development and operating costs of the responsible public agencies or private firms. Indeed, in most cases, it is impossible to separate out the costs and revenues specifically attributable to the people mover system, as there is no separate accounting for these. An exception is at Walt Disney World, where the cost of maintaining the Monorail is financed out of the general admission revenue, with $2.00 of the ticket price designated to cover people mover operations.

Detroit and Miami used different financing techniques to fund the nonfederal portion of their people mover system capital costs. In Detroit, the state of Michigan financed all 20 percent of the nonfederal share of total capital costs; the city of Detroit, however, furnishes all of the necessary operating subsidy. In neither case was a dedicated tax or any sort of innovative financing technique used. In Miami, the state of Florida and the city of Miami each paid for 12.5 percent of total construction costs, with the remaining 75 percent financed by the federal government, as noted previously. To help raise its portion of the capital subsidy, Miami levied a special-district property tax of 15 cents/ft^2 of leasable commercial floor space in the area served by the people mover system. For its share of the project, the state used accumulated highway toll revenues specially earmarked for this purpose. As in Detroit, the operating subsidy in Miami comes exclusively from the local government; no earmarked taxes are used to finance this contribution.

For the most part, therefore, even downtown people movers have been financed by rather conventional means. Only the Miami system used any of the long list of innovative financing techniques available—namely, the special district assessment—and this funded less than one-seventh of the total capital cost and none of the operating costs. This does not imply that the innovative financing alternatives are not appropriate, but rather, that they have little track record. They may be somewhat undependable revenue sources, and sole reliance on them could be risky.

TABLE 2 FARE STRUCTURES ON SELECTED PEOPLE MOVER SYSTEMS

System	Base Fare	Other Aspects
Detroit, MI (inner city)	50¢	Flat fare[a]
Miami, FL (inner city)	25¢	Flat fare[a,b]
Tampa, FL (Harbour Island access from CBD)	25¢	Flat fare[a]
Morgantown, WV (campus connector)	50¢	Free to UWVA students[c]
Duke University (hospital connector)		Free
Atlanta, GA (airport)		Free
Orlando, FL (airport)		Free
Miami, FL (airport)		Free
Tampa, FL (airport)		Free
Dallas, TX (airport)		Free
Houston, TX (airport)		Free
Seattle, WA (airport)		Free
Busch Gardens (amusement park)		Free[d]
Walt Disney World (amusement park)		Free[e]
Kings Dominion (amusement park)		Free[d]
Minneapolis, MN (Zoo)		Free[d]
Miami, FL (Zoo)		Free[d]

[a] No additional fare charged for longer rides.

[b] Passengers transferring from the feeder line, Metrorail, ride free.

[c] Although no fare is charged to students for individual rides, part of the student fees goes toward financing operating costs.

[d] The fare is included in the general admission price, but it is not possible to determine how much this entails in each case.

[e] $2.00 of the admission price to Walt Disney World is earmarked for the Monorail.

Source: Data compiled from information provided by individual systems.

Criteria for Choosing Financing

Before commencing a detailed analysis of the possible funding sources for the proposed people mover in Atlantic City, the three main criteria of public finance are reviewed. The benefit principle states that a public project should be financed such that the cost is borne primarily by those who benefit most from the project. The second criterion regards the distributional impacts and argues for a financing arrangement that places the least burden on the poor, as they are the least able to afford such costs. This is referred to in economics as the "ability-to-pay principle." The third criterion calls for the so-called "internalization of external costs." If automobile drivers, for example, cause congestion and pollution through their use of automobiles, they should be forced to pay for these external social and environmental costs through charges, tolls, or taxes of some kind. To the extent that public investments are necessary to deal with the negative side-effects of automobile use, such charges should be levied on automobile users.

These criteria begin to form a rationale for choosing a funding package for the people mover in Atlantic City. It may be that political or legal considerations prevent the adoption of the alternative that is optimal from a social, economic, and environmental viewpoint. Nevertheless, it is necessary at least to identify the optimal solutions to the financing problem and thus to see clearly the potential sacrifices made in selecting any given funding option.

Evaluation of the Most Plausible Financing Possibilities

For various reasons, only a subset of the financing techniques presented in Table 1 are likely candidates for adoption in Atlantic City. General increases in the property or sales taxes, for example, would satisfy neither the benefit principle nor the ability-to-pay principle. Nor would they in any way internalize the external costs of congestion or pollution. Moreover, there would be intense political opposition to such taxes for financing the people mover. A tax on all earned income in Atlantic City would be opposed for similar reasons. It would additionally place most of the burden on Atlantic City residents and thus encourage out-migration to the suburbs, discourage development in Atlantic City proper, and certainly exacerbate the congestion problem by generating even more commutation from suburban residences to Atlantic City employment locations. A special gasoline tax or motor vehicle tax for residents and employees in Atlantic City would be futile, because it would be easy to avoid and would force the residents, as customers of local gas stations, to bear most of the burden of financing the people mover. The lottery proceeds in New Jersey are already dedicated to educational uses, and there is little chance that they could be—or even should be—used for financing a people mover. By contrast, the alternatives presented in Table 3 represent more plausible possi-

TABLE 3 ADVANTAGES AND DISADVANTAGES OF ALTERNATIVE FINANCING POSSIBILITIES

Financing Technique	Advantages	Disadvantages
1. Passenger Fares	Would satisfy benefit principle; those riding the people mover system would benefit most directly from it; thus they should help finance it.	Fare collection would delay boarding, thus increasing trip times.
	Would be capable of financing most if not all of the system's annual operating and capital costs.	Installing fare collection equipment would require additional capital expenditures and at least some costs for surveillance to prevent fare evasion.
		Depending on fare level, may be regressive financial burden for low-income Atlantic City residents.
2. Parking Tax	Easy to administer, easy to monitor.	Would result in very uneven burdens for the casinos, depending on number of parking spaces; would perhaps unfairly penalize casinos that have provided much parking for visitors.
	Since car traffic generates much of the congestion and pollution in the city, it should also bear much of the burden of the transport investment needed to alleviate this.	
	Would discourage single-occupant cars from driving into the city—thus favorable impact on travel behavior; would also encourage mass transit use.	Probably need to vary rate of tax by location of parking. This would somewhat complicate the tax.

TABLE 3 (*continued on next page*)

TABLE 3 *(continued)*

Financing Technique	**Advantages**	**Disadvantages**
	Not a regressive tax: car owners have a higher average income than those without cars. Would encourage conversion of land being used unproductively as parking to higher-productivity uses. Would also discourage speculation by making land holding in the form of parking more expensive, thus would encourage development.	Not likely to be popular with the Atlantic City business community (including the casinos).
3. Bus Management Fees	Since system is primarily for transporting bus passengers, this fee reflects at least somewhat the benefits derived from the new system by the bus companies and riders.	Would yield only a small portion of total cost—even at $20 per bus, it would only cover about 1/6 of total capital costs.
	Current fee ($1) is very low, easy to collect; even at $20 per bus, it would not be more than what the casinos voluntarily give *each* passenger to spend in their casinos.	By increasing the cost of buses, it might slightly discourage transit use, whereas transit use ought to be encouraged.
		Only a portion of the increased revenue would be likely to be allocated to the people mover; ACTA would need to appropriate the rest for other purposes.
4. Toll on Access Roadways	Would force those who create congestion and pollution problems to help finance transportation investments needed to alleviate these.	Legal problems in implementation. Perhaps practical problems of setting up toll plazas.
	Would discourage unnecessary trips into Atlantic City.	Might slightly discourage some visitors from coming to Atlantic City at all.
	Would encourage ridesharing (carpooling and vanpooling).	Could worsen congestion and air pollution problems on the three major access roads as the tolls impede the flow of traffic.

TABLE 3 *(continued on next page)*

TABLE 3 *(continued)*

Financing Technique	**Advantages**	**Disadvantages**
	Would encourage use of people mover from fringe areas to inner city.	Could have effect of increasing traffic on the three minor entranceways to Atlantic City—Brigantine Blvd., Ventnor Ave., and Atlantic Ave.
	Great revenue potential; even at low rate, would almost completely finance people mover system.	
	Of all techniques, corresponds best to the economic principles of optimal pricing and optimal public finance.	
	Has best impact on travel behavior.	
	Favorable equity impact.	
	Many precedents for this earmarking of toll proceeds for mass transit in NJ, NY, PA.	
	Would be easy to exempt Atlantic City residents from tolls; and this exemption would not substantially reduce revenues.	
5. *Luxury Tax*	Would primarily be paid for by casinos and hotels, which generate most of the traffic leading to the congestion and pollution.	Would not generate that much in revenue; would have to be supplemented by other taxes, charges.
	Positive distributional effects: payers have above-average incomes.	Is not much related to travel behavior; does not discourage single-occupant auto use; does not encourage transit use.

TABLE 3 *(continued on next page)*

TABLE 3 (*continued*)

Financing Technique	Advantages	Disadvantages
	Since main purpose of people mover is to transport casino patrons, only fair that casinos should bear most of the financial burden.	Does not affect all generators of traffic; only hotels and casinos affected.
		Current exclusion of casino complimentaries from base is big loophole leading to lost revenue and distortions in casino policies to minimize tax payments.
		Current luxury tax proceeds are dedicated to new convention center, and its financing needs far exceed the current revenues generated by the tax. Thus, unlikely that even increases in tax could be earmarked for transit.
6. *Employer Payroll Tax*	Forces casinos and hotels to contribute most of the financing cost of new people mover; fair since they generate most of the traffic leading to the congestion and pollution problems that make the people mover necessary; employers are ultimately responsible for most traffic generation in Atlantic City, whether work trips by employees or trips made by customers.	Might be regressive if simply per head tax and if employers shift these taxes to the employees in the form of lower wages. Might discourage the expansion of casinos in Atlantic City; might discourage development of new businesses, hotels in Atlantic City and instead encourage them to locate outside Atlantic City.
	Depending on rate, could raise up to half of total financing needed for the people mover system and would certainly be sufficient to cover operating costs.	Would require state approval, possibly special legislation; no precedent for this in New Jersey.
	Would be easy to monitor and collect.	
	Satisfies benefit principle of taxation; those who benefit most from people mover would have to finance it.	

TABLE 3 (*continued on next page*)

TABLE 3 (*continued*)

Financing Technique	Advantages	Disadvantages
	Precedents in Portland (OR) and *all* French cities, where entire transit subsidy is financed by such payroll taxes.	
	Would not create any direct financial burden either for Atlantic City or Atlantic County governments.	
7. *Value Capture*	By focusing on the area served by the transport investment, forces those most benefited by it to contribute to its financing.	Would primarily show up in the future; very uncertain exactly how much new development will be induced; thus uncertain how much value can be captured by this financing method. Would be many years until this could make a substantial contribution to financing.
	Especially useful for future expansion of the system and perhaps for financing of operating costs.	
	To the extent that it entails increases in the property tax proceeds (at constant tax rate) that arise from increases in land and property values resulting from the transport investment, this is a way for the public to share in the return and to finance the investment.	Exact determination of district boundaries is certain to be very controversial; they will be difficult to determine objectively.
8. *Joint Development*	Ideal for financing capital costs of stations.	Hard to predict in advance exactly the extent of funding potential; good supplement to other more predictable, more comprehensive funding sources, but a poor base for funding in itself; in other cities, has yielded only a very small percent of total funding requirements.
	Good match between benefits of investments and contributions to financing.	
	Can be used to pay for investments that enhance mutual attractiveness of transport investments and adjacent development;	

TABLE 3 (*continued on next page*)

TABLE 3 (*continued*)

Financing Technique	Advantages	Disadvantages
	encourages better access opportunities and higher land densities around stations; encourages coordination of land-use development with mass transit.	
9. Turnkey Development	Eliminates much of public sector interference in projects; increases room for ingenuity, creativity; technological and productivity improvements on the part of private contractors.	Not much track record with this approach; not clear if it will really work.
	By establishing one fixed, overall price for the project, eliminates the risk of cost overruns for the city.	Crucial to find overall contractor with sufficient assets to ensure that he can absorb cost overruns and really guarantee completion of the project at the agreed-on cost.
10. Private Ownership and Management	Might lead to higher productivity, more efficiency, lower costs, better service.	Perhaps not enough public sector control of the system.
	Would not strain the administrative, managerial capacity of the existing public bureaucracies in Atlantic City; would insulate the project somewhat from costly, time consuming and distorting political factors that might plague a publicly run system.	Private operator-developer would obviously demand a price for this service, either directly or indirectly; cost may be hidden in form of profits from land-development gains; allows private sector to capture the profits from development potential in Atlantic City.
	Minimizes financial risk to city; risk instead borne by private shareholders.	Essential to choose really reliable, responsible, financially strong firm; otherwise, will not work.

bilities for funding the people mover. The advantages and disadvantages of each alternative are also presented in detail in the table, so that they will be only briefly highlighted here in the text.

Fare Box and Other System-Generated Revenues

Perhaps the most promising revenue source is the fare box. Unlike all other urban transit systems, where fares pay only a portion of total operating costs and none of the capital costs, an Atlantic City people mover could probably be self-financing. Transit ridership is not sensitive to fare levels even on conventional transit systems (*14*). Fare elasticity would be even lower in Atlantic City. With a mandatory casino bus and employee car intercept that is handled efficiently and smoothly, moderate fares would probably not discourage much ridership at all. Furthermore, with possible casino subsidy of the fare, the out-of-pocket cost to the rider could be minimal. Having to pay an extremely high people mover fare might induce some bus visitors to drive to Atlantic City, or not come at all, but it is improbable that moderate fares would have such an effect. Visitors would be more inclined to switch to private transportation modes if the transfer from bus to people mover proved too confusing, fatiguing, or time consuming. High fares, such as $5 a ride, would discourage ridership primarily for discretionary casino-to-casino trips. However, as shown in Table 4, the high projected ridership should be sufficient to keep break-even fares around $1.25 per ride for the Boardwalk and Marina-Boardwalk route configurations and $1.75 for the central core configuration, and still cover most if not all total annual operating and debt service costs. Break-even fares for the smaller central core configuration would be about 50¢ higher because the system would carry only a fraction of all casino bus passengers and would be unable to provide intercasino service.

In addition to its revenue potential, fare box financing would be consistent with the benefit criterion of transit finance that

TABLE 4 PROJECTED ANNUAL RIDERSHIP, COSTS, AND REVENUES BY THE YEAR 2000 (IN MILLIONS)

	Central Core Scenario	Boardwalk Scenario	Marina-Boardwalk Scenario
Total Annual Trips	11.1	39.5	46.9
Total Annual Costs			
Operating and Maintenance	$ 4.3	$10.2	$13.0
Debt Repayment	$15.3	$40.3	$48.6
TOTAL	$19.6	$50.5	$61.6
Annual Fare Box Revenue			
@$1.00 Fare	$11.1	$39.5	$46.9
@$1.25 Fare	$13.9	$49.4	$58.6
@$1.50 Fare	$16.7	$59.3	$70.4
@$1.75 Fare	$19.4	$69.1	$82.1
@$2.00 Fare	$22.2	$79.0	$93.8
Annual Advertising Revenue			
@1.5 cents per passenger	$.17	$ .59	$ .70
@ 2.0 cents per passenger	$.22	$ .79	$ .94
@ 3.0 cents per passenger	$.33	$1.20	$1.40

Note: Calculations assume zero elasticity of demand. To the extent that fare elasticity does exist, these figures overstate actual revenues. Boxed areas indicate approximate break-even costs and revenues.

those using the system should bear most of the cost of financing it. Fares are also the most preferred financing alternative among the 60 Atlantic City stakeholders interviewed for the Rutgers study. More than 90 percent favored using fare box revenues to help finance a people mover system. No other funding option elicited such widespread support.

The people mover system could also generate other revenues besides fares, such as income from advertising. Almost all United States transit systems sell advertising space in their vehicles and stations. Annual advertising revenues vary from just $100,000 in the new MAX light rail system in Portland, Oregon, to more than $1 million in Atlanta's MARTA metro rail system (R. K. Buis, Vice President, AMNI/Winston, Inc.; and John R. Jost, Vice President, Transit Ads, Inc., unpublished data). As these examples indicate, advertising provides a modest supplement to the fare box; by itself, it covers only a small fraction of a system's operating or capital costs. According to a 1985 survey of United States transit systems, average annual transit advertising revenues amount to about 1.5¢ per passenger trip (*15*).

Advertising revenues vary according to the size of the system, the number of passengers carried, the availability of alternative advertising outlets, and the nature of the market (e.g., commuter versus tourist). Assuming advertising in vehicles and stations is permitted, there would almost certainly be a robust advertising market in Atlantic City. As already shown by the numerous casino billboards positioned along the three main Atlantic City access roads as well as the smaller illuminated signs perched atop hundreds of New York City taxicabs, casinos have an avid interest in informing potential visitors of their attractions. With almost 50 million annual riders projected for the Marina-Boardwalk system, a people mover would generate a larger advertising market than any of the three major Atlantic City entranceways. Assuming, for example, an annual rate of 3¢ per passenger trip, a Marina-Boardwalk system could generate $1.4 million in advertising revenue, a minor but certainly not unwelcome annual revenue stream (see Table 4).

State, County, and Local Revenue Sources

Apart from fare box, advertising, and other system-generated revenues, the only other funding sources involve government subsidy. Some portion of annual capital and operating costs could be paid by various taxes and fees.

Parking Stall Tax. A potential funding source for people mover development could be a per-space parking tax levied on all parking spaces in Atlantic City. Unquestionably, this tax would increase the cost of automobile use and would encourage at least some current automobile users to switch to mass transit. The tax could be differentiated so that it would be highest for those parking places nearest the Boardwalk and lower for parking spaces toward the fringes of the city. Such a parking tax would be equitable and would also encourage more environmentally responsible behavior on the part of automobile users. In addition, such a tax would be a strong inducement to use the people mover system instead of driving into the city center. Thus, parking taxes would both finance the people mover system and encourage use of the system. In this respect, the proposed access roadway tolls and parking taxes are unequaled as methods of people mover funding. As presented in Table 5, annual parking tax revenue could range

TABLE 5 REVENUE POTENTIAL OF ALTERNATIVE FUNDING SOURCES

Tax or Fee/Base and Rate	Annual Revenue (in millions)
1. Stall tax on off-street parking[a]	
$ 5/month/space	$ 1.9
$10/month/space	$ 3.8
$15/month/space	$ 5.7
$20/month/space	$ 7.6
$30/month/space	$11.3
$50/month/space	$19.0
2. Increasing bus "management" fees charged by ACTA	
$ 1/bus (current level)	$ 0.4
$ 5/bus	$ 2.0

TABLE 5 (*continued on next page*)

TABLE 5 (*continued*)

Tax or Fee/Base and Rate	**Annual Revenue (in millions)**
$10/bus	$ 4.0
$20/bus	$ 8.0
3. Imposing one-way in-bound tolls on the three main access roads to Atlantic City[b,c]	
$1 toll per vehicle (excluding buses)	$24.0
$2 toll per vehicle (excluding buses)	$48.0
4. Changes in current luxury tax	
If ad valorem tax:[d]	
Increase rate from 12% to 15%	$ 5.0 (more)
Return of 3% state portion to city	$ 5.0 (more)
Include complimentaries from casinos in tax base	$10.0 (more)
Shift to per-room tax:[e]	
$ 500/room/year	$ 9.0 (total)
$1,000/room/year	$ 18.0 (total)
$2,000/room/year	$36.0 (total)
5. Employer payroll tax [f]	
If head tax on hotel and casino employees:	
$100 per year	$ 5.5
$200 per year	$11.0
$300 per year	$16.5
If ad valorem:	
0.5% of payroll	$ 7.0
1.0% of payroll	$14.0
2.0% of payroll	$28.0
If head tax on all private sector employees:	
$100 per year	$ 6.5
$200 per year	$13.0
$300 per year	$19.5

TABLE 5 (*continued on next page*)

TABLE 5 (*continued*)

Tax or Fee/Base and Rate	Annual Revenue (in millions)
If ad valorem:	
0.5% of payroll	$ 8.0
1.0% of payroll	$16.0
2.0% of payroll	$32.0

[a] This tax could be differentiated by location, with lower taxes levied in fringe areas and higher taxes in central locations. Currently, there are 31,439 spaces.

[b] These calculations assume zero demand elasticity. To the extent that traffic demand is reduced, toll revenues will be less than calculated, but virtually all studies show a very low elasticity for roadway tolls. Thus, proceeds from such a toll in Atlantic City would not be substantially lower than these calculations. Currently, there are about 65 million vehicles entering per year.

[c] Residents of Atlantic City comprise a small portion of total auto drivers on these routes. Exempting them from this toll would not substantially reduce overall revenues.

[d] Currently yields $15 million per year.

[e] Assuming 18,000 hotel rooms.

[f] To be paid by employers in proportion to number of employees or as percent of payroll.

from $1.9 million annually from a $5/month per stall tax, to $19 million annually from a $50/month per stall tax.

Although a parking stall tax would probably not require enabling legislation, it would be opposed strongly by casinos and owners of other off-street parking facilities. Faced with a $25/month tax, for example, a 500-space garage would be assessed a $150,000 annual surcharge. A $50 tax on a 1,000-space facility would cost garage owners $600,000 annually. A parking tax is also not popular among the Atlantic City area government officials and business executives interviewed for the Rutgers study. Opposition is particularly strong within the city government and the casino industry—two strong voices in local decisions. Nevertheless, almost half of all the respondents who voiced opinions on this matter favored a parking stall tax.

Bus Management Fees. Currently the Atlantic County Transportation Authority (ACTA) collects a bus management fee of $1 per casino bus for intercepting them at the city periphery and coordinating their trip further to the individual casinos so as to mitigate traffic congestion. Increasing casino bus management fees above their present level of $1 per bus would not require any additional administrative apparatus, and some might argue that the fee is too low anyway. It has remained unchanged since ACTA was formed almost 10 years ago. Because one of the stated goals of a new people mover system would be to get the buses off the streets of Atlantic City by intercepting them outside the city, it may seem appropriate that bus operators and passengers (or their casino sponsors) should pay to finance the people mover in proportion to the number of buses serviced at the intercept point. The main disadvantage to this option is that it would increase the price of transit travel into Atlantic City but would leave the cost of auto use unchanged. That might encourage a shift from transit to the auto, the worst possible scenario. Moreover, any effort to increase bus management fees is likely to be challenged vigorously by the Atlantic City Bus Operators Association, an organization formed by the major bus companies providing Atlantic City service. Even if an increase were granted, the amount of additional revenue available to meet capital and operating costs would be modest. As shown in Table 5, a $20 bus management fee would generate approximately $8 million a year, just 13 percent of the estimated $61.5 million required to meet a Marina-Boardwalk system's annual debt and operating costs. On the other hand, this amount of revenue could cover more than 60 percent of the system's annual operating and maintenance costs.

Tolls. At least from an economic point of view, one of the most attractive financing possibilities would be a toll on the three approaches to Atlantic City—the Black Horse Pike, the White Horse Pike, and the Atlantic City Expressway. Such a system of tolls would satisfy all the criteria of optimal public finance and would contribute greatly to alleviating the congestion and pollution problems caused by excessive traffic in Atlantic City. Moreover, it would strongly encourage people to park in fringe lots and to take the people mover into the central city. As was the case for parking surcharges, such tolls would not only help finance the people mover, but would also help encourage its use. As shown in Table 5, imposing a $1 toll on the three main access roads to Atlantic City could generate as much as $24 million annually, or 39 percent of the total capital and operating costs of a Marina-Boardwalk people mover system.

There would, however, be some problems with the implementation of a toll system. Allocating Atlantic City Expressway Authority revenues to the people mover would require approval by the governor and legislature. In addition, tolls could worsen traffic congestion and air quality conditions on the outskirts of Atlantic City by impeding the flow of traffic on the three major access roads. Tolls could also induce additional traffic on the three minor approaches to the city—Brigantine Boulevard, Atlantic Avenue, and Ventnor Avenue—thereby increasing congestion and pollution in several residential areas. Another problem concerns the installation of tolls on the White Horse and Black Horse Pikes. Because these roads are maintained with financial assistance from the federal government, federal regulations would require the state to pay back the costs of the previous subsidies if they were to become toll roads. Toll revenues would thus have to be used to reimburse Washington in addition to financing the people mover.

Even if additional tolls were not charged on the city's three major entranceways, it might also be possible for the people mover to receive financial support from the Atlantic City Expressway Authority and perhaps the Garden State Parkway Authority. Such use of highway toll revenues, of course, would require approval from the state government. Even if such approval were granted, the Atlantic City Expressway and Garden State Parkway Authorities would probably be able to furnish only a fraction of the total revenues needed to meet the people mover's annual debt and operating costs.

Luxury Tax Supplement. A supplement to the current luxury tax in Atlantic City might also be a possibility. It would be paid primarily by casino and hotel visitors, and thus would not burden residents. Depending on the amount of the increase and how it is structured, a luxury tax supplement could yield $5 to $21 million in new revenue (see Table 5). Because the proposed people mover system is primarily intended to serve casino and hotel visitors, this form of financing would satisfy the benefit principle of taxation. The main problem is that luxury tax proceeds are currently dedicated to the new convention center; even at the current rate, the luxury tax is not generating enough revenue to finance this project. It is, therefore, unlikely that any increases in this tax would be dedicated to the people mover over the convention center. A luxury tax supplement is also opposed by most of the stakeholders interviewed for this study; three-quarters of the respondents were against the idea.

Employer Payroll Tax. An employer payroll tax would also satisfy the benefit criterion, in that casino and hotel employees would be heavy users of the system. It would thus represent a contribution by their employers for their transportation. There is considerable precedent for earmarked employer payroll taxes to finance mass transit. Portland, Oregon, has used such a tax for over a decade with great success. Moreover, financing for a proposed downtown people mover in Denver included a dedicated employer payroll tax in a special assessment district around the system route. In France, virtually all cities levy an employer payroll tax to support both operating and capital costs of mass transit, and this tax is willingly accepted by employers, who view it as a means of facilitating the transportation of their workers. If such a tax were introduced to Atlantic City, the data presented in Table 5 indicate it could produce $5 to $30 million a year.

To introduce an employer payroll tax in Atlantic City might be difficult, however, because of the need for state approval. Moreover, such a tax might encourage new noncasino development to take place outside Atlantic City proper or the special assessment district—however that is defined—to avoid the tax. An employer payroll tax could thus be at odds with the economic development goals of an Atlantic City people mover.

Experimental or Innovative Financing Options

The various innovative financing options could all be used to some extent in the Atlantic City context—and they should be, where feasible—but it is highly unlikely that they can provide major funding for the system. The value capture options, for example, produce revenues mainly in the future, after the people mover system would be in operation, and the actual amount of such revenues is impossible to predict. Moreover, this technique does not have much track record in the United States; even where it has been used (in San Francisco, for example), it has financed only a small percentage of system costs. Its appropriateness for Atlantic City is also uncertain. A special assessment district stretching along the people mover route, for example, would inevitably fall on what is already the most heavily taxed area in Atlantic City—that between Atlantic Avenue and the Boardwalk. Any effort to further increase property taxes in this section is bound to face stiff opposition from casinos and other property holders.

Likewise, joint development sounds like a good idea, but no system in an urban context—such as Atlantic City—has been financed in this manner to any significant extent. Joint development can certainly provide supplemental revenues and thus reduce the required public financing, but it would be foolhardy to rely solely on this set of options. The one exception to this is the financing of people mover stations by the casinos they will serve. The casinos have indicated that if a system were built, they may not object to financing their own stations, as this enhances their accessibility to the system and gives them a say in station design. The bus intercept facility might also be a successful candidate for joint development. The large number of casino visitors and employees passing through the facility could encourage associated commercial development.

Fully private ownership, construction, operation, and management would be the most extreme form of private sector participation in the people mover project. In theory, of course, it sounds very attractive, because one assumes that this would minimize the costs to the public. Although the obvious, so-called accounting costs to the public may be minimized by such a funding option, other types of costs may not be adequately taken into account by this method. With total private ownership and control, the city and other government agencies might be constrained in their ability to regulate fares or exercise oversight or control over the system. Public authorities responsible for choosing a financing method should be especially careful about what they are giving up in public control by allowing private firms to design, build, operate, finance, and manage the system. To the extent that vendors may also be interested in land development opportunities around the stations and perhaps the intercept facility, public authorities should be aware of the potential revenue losses that could result from tax abatement or exemption clauses included in the development agreement.

Except for Las Vegas, not a single downtown people mover system has been financed exclusively or even to a significant extent by private ownership. Thus, Atlantic City decision makers must realize that they would be taking somewhat of a risk with this untried method.

CONCLUSIONS

An Atlantic City people mover would probably be an anomaly in urban mass transit. Whereas virtually all urban transit systems operate at a loss and require federal or state subsidies to cover much of their operating costs and all of their capital costs, an Atlantic City people mover could probably support itself through fare revenues. Because of high projected ridership, made possible in part by a mandatory bus and casino employee intercept, fares could probably be kept in the range of $1.50 to $1.75, and yet be sufficient to cover annual debt service and operating costs. Few other urban transit systems in the United States can make similar claims. Of course, it remains to be seen if fare financing would in fact be sufficient to cover all construction and operating costs, but projections suggest this to be the case.

Although fares cover only a small part of the operating budgets and none of the capital costs of United States transit systems, they seem to be the most feasible option for Atlantic City. Federal subsidies, barring a major transportation policy reversal by the Bush administration, are extremely unlikely. The state, county, and local taxes, fees, and other revenue sources reviewed previously could generate varying amounts of revenue, but they would confront intense political opposition in Atlantic City if not at the state level as well. One important consideration in relying on these other revenue sources is that, except for the toll option, the financial burden would be borne primarily by the casinos. Having the casinos finance their own stations, pay special assessment taxes, parking stall taxes, or payroll taxes, as well as subsidize the fares of their employees and perhaps their customers, would in effect shift the system's entire financial burden to this portion of the local economy. Because their patrons would be the main users of the system—and currently cause the congestion and pollution problems the people mover is intended to alleviate—it seems only fair that the casinos and their patrons should bear a substantial portion of the costs.

In evaluating the feasibility of state, county, and local revenue sources for transportation finance, it is essential to remember that even if any of these revenues became available, it is far from certain that they would be allocated in sufficient amounts to a people mover. Unless the people mover can fund itself through fares or other system-generated revenues, it stands as one of numerous proposed capital projects in competition for scarce resources. In Atlantic City alone, convention center construction efforts are dragging for want of adequate support; the upgrading of the Atlantic County International Airport (Pomona) is indefinitely delayed; and funds needed for a new solid waste disposal facility have yet to be found. In the state as a whole, several transportation projects already in the final design phase await funding for implementation. Just maintaining and improving New Jersey's Interstate highway network will take up most of the state's transportation capital budget for years to come. Of the federal transit subsidies still remaining after years of cutbacks, virtually all are already committed to New Jersey Transit. Were the people mover to require state, county, or local subsidies for capital or operating costs, the timing and availability of such assistance would depend on the people mover's priority relative to other proposed and already scheduled capital projects.

As a practical matter, the most feasible alternative for financing the people mover appears to be fare revenues, especially considering the political, fiscal, and economic realities facing Atlantic City and New Jersey. In relying on this mode of transit finance, it is critical to ensure that the mandatory intercept of casino bus passengers and commuters does not deter visitors from using buses to reach Atlantic City. A modal shift from transit to the automobile would greatly exacerbate the very congestion and pollution problems a people mover is intended to mitigate.

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Using Value Enhancement To Finance People Movers in Suburban Activity Centers

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Traffic relief that permits an additional increment of development is the foundation for public-private cooperation in building people movers to serve suburban activity centers. The most important variables in assessing economic potential are land prices, scale of the activity center, and degree of congestion relief that the project will bring. Using people movers as circulation systems to reduce internal, site-specific automobile trips is unlikely to justify significant private investment. However, reducing regional automobile use through strategies that incorporate people movers can generate economic value. People movers, therefore, are viewed as passenger distribution systems that disperse travelers arriving on a variety of regional transport modes to destinations throughout the activity center. The distribution or circulation systems are envisioned as a mix of walkways and people mover technologies, with an emphasis on flexibility and phased implementation. Shuttles and miniloops operating at close headways are more likely to find application than grand loops linking a few key locations. Revenues from the sale of new development rights, property taxes, special assessments, public matching funds, and user fees are projected for activity centers of varying sizes to derive financing scenarios for congestion mitigation systems. Certain institutional problems in implementation are presented and a profile of activity centers most likely to be candidates for people movers is discussed.

The major transportation problem of activity centers is congestion. Unless people movers find a role in traffic mitigation, their deployment in suburban commercial areas will remain a novelty.

Developers must be convinced to invest by value, not faith in engineers and equipment purveyors. Financing infrastructure through public-private partnerships is an economic process. The value created by people movers can be quantified and translated into dollar terms. Do the costs exceed the level of justifiable investment, leaving politics and other intangibles aside?

People movers have been applied successfully at airports, as downtown circulators, and as shuttles capable of overcoming distances or physical barriers (such as rivers, railroad tracks, and highways) to link outlying development projects with high-value locations. Why haven't the economics justified more projects in suburban activity centers?

The approach traditionally used to assess project feasibility is to have system planners determine the optimum solution. The resulting bottom-line is then given to the finance group to find the money. This review takes the opposite tack—it seeks to quantify the value a people mover can create and then challenges the technicians to find solutions that fit the pocketbook.

Perhaps defining the envelope of economic viability will lead to more, as well as better, technology applications.

ASSUMED CONGESTION MANAGEMENT STRATEGY

Assuming that people movers can help manage congestion in suburban commercial zones, an approach to traffic abatement is postulated that involves constructing linkages between buildings and projects within activity centers, integrating uses to maximize benefits from the linkages, establishing a reinforcing parking policy, and using regional transport modes to feed the internal circulation system.

In today's activity centers, the distances between buildings, frequent lack of sidewalks, limited mix of uses, absence of weather-protected linkages, and plentiful free parking promote automobile use. Building a strong circulation system will tend to minimize internal automobile trips. However, the level of trip reduction on a site-specific basis is unlikely to justify the economics of people mover technology.

Reducing traffic at the regional level is needed to permit meaningful private investment. Incorporating people movers into an internal distribution system that efficiently disperses workers and shoppers arriving at the commercial area's periphery on regional feeder modes (such as heavy rail, express bus, HOV lanes, light rail, vanpool, and ridesharing) could achieve this goal. The distribution system must connect scattered destinations throughout the activity center quickly and conveniently to promote usage.

The internal system cannot succeed in its traffic reduction mission without supporting investment in regional transport.

THE PEOPLE MOVER'S ROLE

It is assumed that people movers only will be built where justified by distances and passenger densities. The postulated passenger distribution system may be a mix of walkways, moving sidewalks, and people movers. Along legs where large, undeveloped spaces exist within activity centers (and fixed facilities cannot be justified until in-fill sites are built out), it may even be appropriate to run shuttle vans on a temporary basis. It is also possible that a mix of people mover technol-

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ogies may be used because of differing density, distance, reliability, or cost considerations.

Investing large sums in infrastructure before generating income to pay for it is a well-traveled route to financial disaster. Staged circulation system implementation that retains maximum flexibility is vital in suburban commercial centers, where multiple sites under different ownership are involved and no predictions can be made regarding the order in which projects will come on stream.

Few generalizations about distribution systems, beyond the need for flexibility, are possible because suburban activity centers themselves defy generalization. They come in all sizes and shapes—some linear, some clustered—and are even hard to define. Some may be served by highway only, whereas others may be accessed to varying degrees by public transit systems (Bethesda, Md., and Tysons Corner, Va.).

As a result, the people mover building block is assumed to be the shuttle or miniloop—an approach contrary to the assumption that passengers don't want to make transfers. Although admittedly less than ideal, the positives of a building block approach, in terms of opportunities for phased deployment, reduced cost, and enhanced flexibility, far outweigh the negatives.

Ridership models are sensitive to transfers, speed, and other factors that influence the cost of people movers. However, patronage projections have no value in financing fixed guideway systems—no one in the United States accepts fares as a core revenue source to cover capital outlays.

Given the lack of credence placed in farebox projections by the financial markets, why allow patronage models to bias technology choices toward uneconomic solutions?

To maintain speed and limit passenger frustration, minimal waiting times at intersection points can be specified. Connecting walkways and transfer stations also can be income-generating locations for service and retail activity, automatic vending, advertising, etc., as well as sites for day care centers or other uses that minimize automobile trips.

The grand loop that seeks to serve an entire area with a single technology is costly and unlikely to be sufficiently flexible to suit the hodge-podge development pattern that exists in most activity centers. Such systems may be appropriate for new centers, like Los Colinas, that are master planned with people movers in mind.

Incrementalism also can lower the stakes of individual decisions so that implementation does not get bogged down. Delays in resolving alignment and technology selection are anathema to private developers, whereas the attendant bickering among vendors and consultants gives credence to latent concerns over reliability and cost overruns. The clamor and delay often cause well-proven people mover technology to lose credibility.

Smaller-scale projects can be, and should be, left in the hands of private developers to implement themselves. Because activity centers typically involve many development sites with multiple buildings on each site, developers can be given a set of performance standards to meet in devising solutions appropriate to their project's design, market, and build-out schedule.

Activity center-wide performance measures, primarily relating to time and convenience factors (to prevent mile-long walkways), allow site-specific distribution systems to be linked into a network that, in turn, interfaces at critical junctures with regional transport modes. System performance standards can be incorporated into zoning codes in much the same way street and utility designs are now specified.

A similar concept was used in Los Colinas to have private developers build sections of the guideway as part of their site improvement requirements. Private, turnkey construction can yield significant cost savings, as well as insulation from the risk of cost overruns.

The role envisioned for people movers will not maximize linear feet of guideway, but it will get systems built when performance requirements dictate and the economics are justified.

GOING-IN ASSUMPTIONS

Free parking and undisciplined land use control will undermine any congestion management strategy. On the other hand, before the automobile option is limited, responsible travel alternatives must be available.

Advocating connections between buildings that network up into a distribution system creates economic and design biases toward clustering development. Property owners and land speculators expecting future sprawl to absorb their sites will not be supportive.

The congestion management strategy previously outlined requires investment in regional transport modes, as well as in activity center distribution systems. Demands on buses, HOV lanes, park-and-ride lots, light- or heavy-rail systems, ridesharing services, etc., will vary by locality. Counties with multiple commercial centers may take different approaches from those with one development concentration. Areas with mass transit facilities face different alternatives than those with none. Depending on existing conditions, the full cost of addressing regional travel needs is likely to exceed the measures presented.

In order to keep the benefits of congestion management investments from being dissipated to neighboring jurisdictions, reinforcing regional growth and tax sharing mechanisms may be needed.

The discussion has been simplified by concentrating on commercial uses in activity centers; however, real-world applications will need adjustments to account for residential, and possibly industrial, uses.

MEASUREMENT OF CONGESTION RELIEF

If traffic can be reduced through abatement strategies incorporating people movers, then the most direct means of creating value is to increase allowable development within the activity center. By increasing development to the same extent automobiles are reduced, new value can be created and net automobile use decreased.

The typical suburban land use requirement of three to four parking spaces per 1,000 ft^2 of commercial development implies about a 1:1 ratio between parking and development area. If a people mover-inclusive traffic mitigation strategy results in, say, a 40 percent reduction in automobile use, then increasing development density by 40 percent still would yield fewer total cars than the base condition. The automobile reduction is assumed to be achieved through a combination of higher auto occupancy and greater use of other modes (transit, walking, bicycle, etc.). The actual proportions will depend on configuration of the activity center and the regional infrastructure in place.

The relationship between reduced automobile use and higher development density is shown in Figure 1.

Calculations for activity centers of different sizes and varying degrees of automobile reduction are derived from the following relationships:

$$B = D(1 - T)/O$$

$$\text{Base number of cars} = SB$$

$$\text{Avoided automobiles} = SBG(1 + G)$$

$$\text{Net automobile reduction with development increase} = SBG^2$$

where

S = Scale of activity center in thousands of square feet;
D = Number of employees per 1,000 ft^2;
B = Base number of cars accessing activity center per 1,000 ft^2;
O = Vehicle occupancy;
T = Percentage using transit, walking, bicycle, etc.;
G = Percent gross reduction in automobiles and development increase.

In a hypothetical case, assume

S = 5,000 (5.0 million ft^2);
D = 3.5 employees per 1,000 ft^2;
T = 4 percent using transit, walking, bicycle, etc.;
O = 1.1 passengers per vehicle; and
G = 40 percent gross reduction in automobiles and 40 percent development increase.

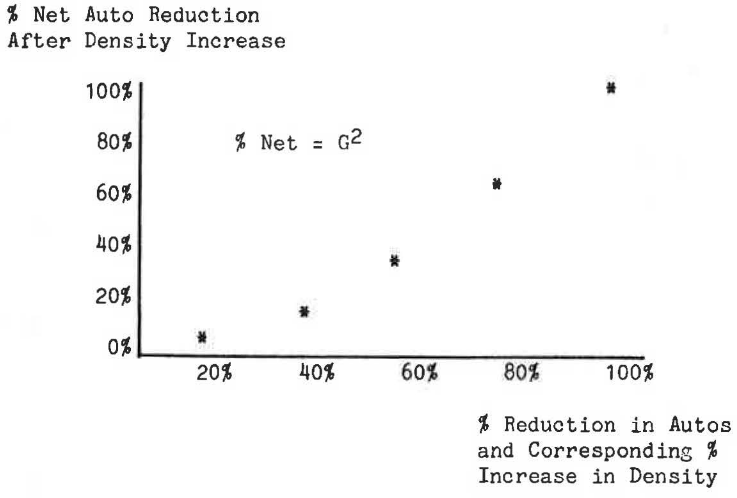
Then B = 3.055 cars per 1,000 ft^2; base number of cars = 15,275 cars; avoided cars = 8,554 cars; and net automobile reduction with density increase = 2,444 cars.

The relationships drawn have simplified the calculation process by assuming a uniform automobile generation rate for all commercial uses and ignoring residential implications. In addition, weighting for peak and offpeak travel has not been incorporated at this stage.

The calculation for avoided automobiles provides an indication of the requirements for alternative transport services. If, in the hypothetical case, 8,554 cars are to be taken off the road, then park-and-ride lots may have to be built, buses acquired, HOV lanes created, and rail vehicles purchased to accommodate the new travel demand. To properly scale new facilities, peak versus offpeak requirements would have to be assessed, as well as commute versus noncommute travel. According to the example shown, plans would have to be made to accommodate 9,409 people, because the cars eliminated had an occupancy of 1.1 passengers.

The exercise demonstrates that capital investment that reduces automobile dependency can create value by permitting more growth to occur. The argument that more development means more cars is not necessarily true—as long as promised levels of automobile reduction are realized. However, when roads are saturated, increasing highway supply without influencing automobile trip generation fails the growth dividend test.

A coordinated investment strategy that creates attractive alternatives to single-occupant automobile travel will affect existing, as well as future, development. The result is more equitable because it does not impose behavior modification



G = % Gross change in autos due to higher auto occupancy (O), and/or a higher non-auto travel share (T), and corresponding % increase in permitted development density.

FIGURE 1 Congestion impact of automobile reduction and higher development density.

programs (carpooling, flextime, etc.) on a limited segment of the development base to solve a general problem. Smaller changes affecting all development can achieve better results than a program to radically modify travel patterns only in new projects, or those above a particular scale.

CONVERSION OF INCREASED DEVELOPMENT INTO VALUE

New Development Density

If traffic reduction measures permit additional growth, land values can translate newly available development rights into dollar terms to cover costs. The calculations are straightforward:

$V = DL$

where

D = Area in square feet of new development permitted,
L = Cost per square foot of development rights, and
V = Value in dollars.

Assume

D = 4 million ft^2
L = $\$35/\text{ft}^2$

Then

$V = 4{,}000{,}000 \times \$35 = \$140{,}000{,}000$

Figure 2 shows values for up to 10,000,000 ft^2 of newly permitted development at prices ranging from $\$10/\text{ft}^2$ to $\$45/\text{ft}^2$.

The cost per square foot of development rights is different from cost per square foot of land. If the allowed density on 1 ft^2 of land is 0.33, which is common in suburban areas, then $\$30/\text{ft}^2$ of development rights equates to $\$10/\text{ft}^2$ of land value Prices around Dulles Airport are in the range of $\$30/\text{ft}^2$ of development, whereas the hottest areas of downtown Washington, D.C., are approaching $\$150/\text{ft}^2$ of development ($1,500/ ft^2 of land at the 10:1 development-to-land ratio prevailing at these locations.)

The creation and conversion of new development density into dollars by public agencies through negotiated arrangements with property owners is the foundation for financing people movers as an element of congestion management systems for suburban activity centers. Inherent in this assumption is the expectation that there will be market demand for the additional development. Therefore, activity centers in the strongest markets will be most likely to use the concepts outlined.

Although the values shown in Figure 2 may be negotiated, public agencies may be able to realize only a portion of the benefits because of absorption rates, bargaining skills, terms and conditions, etc. Variations of the values shown in Figure 2 are also possible—rather than lump-sum dollars, revenues can be derived over time through lease payments or through periodic sales guided by market conditions.

The greatest determinants of capital dollars available for passenger distribution systems are cost per square foot of development rights, scale of the activity center, and level of automobile reduction. There also is interdependence among the key variables because larger activity centers will tend to have higher land prices.

Table 1 indicates how value enhancement can be extended to estimate revenue sources for suburban congestion management systems incorporating people movers. The purpose

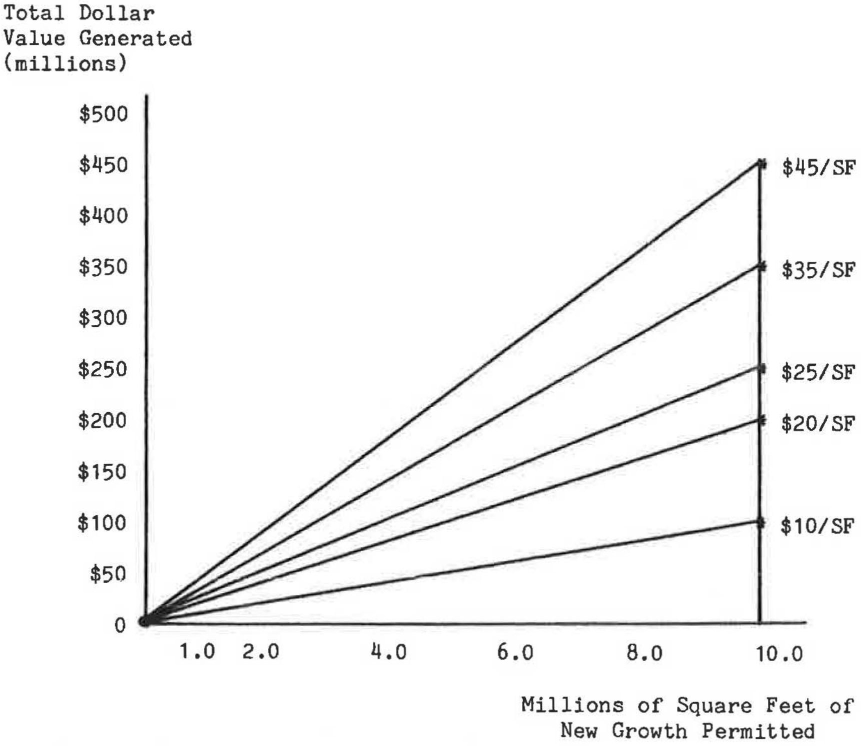


FIGURE 2 Dollar value of incremental growth.

of the table is to convey a methodology for approximating the economic envelope for automobile reduction programs. The model can be adapted to the circumstances and economic relationships in particular activity centers. The remainder of this section describes the four annual revenue sources presented in Table 1.

Property Tax Increment

If a higher level of commercial development is permitted than would otherwise be possible, the locality will realize an increment in property tax revenues. Because commercial properties tend to generate more taxes than they consume in public services, many suburban communities are anxious to attract work sites.

An argument can be made that commercial development represented by the new growth would have occurred anyway, either by expanding the periphery of the activity center, or through evolution of new activity nodes where highway capacity was still available. It is assumed that these alternatives would be perceived as negative from an environmental perspective, as well as from the standpoint of providing public services and utilities over a more scattered area.

The first annual revenue source in Table 1 is based on the property tax increment attributable to new growth permitted by the mitigation program. The figures assume a $2.50/ft^2 property tax rate, which will vary substantially from jurisdiction to jurisdiction. Property taxes in urbanized areas may run above $5.00/ft^2; however, a major attribute of suburban activity centers is that lower occupancy costs and property taxes are a key factor. Again, the idea of the exercise is not to settle on a particular figure, but to lay out a general methodology into which actual values can be incorporated.

A further assumption is that the local jurisdiction will allow 50 percent of the property tax increment to be used for the traffic mitigation program. This is a guess that may be optimistic for some localities and conservative for others.

The key variables to consider in projecting possible local property tax contributions are

TABLE 1 REVENUE POTENTIAL FROM VALUE ENHANCEMENT

Original Development (millions SF)	2.0	5.0	7.5	12.5	20.0
New Density @50% Mitigation (millions SF)	1.0	2.5	3.8	6.3	10.0
Cost/SF Development Rights	$25	$30	$30	$35	$40
Avoided Autos @ 50% mitigation	4,582	11,455	17,182	28,636	45,818
(millions)					
1. New Development Value	$25.0	$75.0	$112.5	$218.8	$400.0
2. Annual Revenue Sources					
Property Tax Increment -1	$1.25	$3.13	$4.69	$7.81	$12.50
Square Foot Assessment -2					
New Development	$1.00	$2.50	$3.75	$6.25	$10.00
Existing Development	$1.00	$2.50	$3.75	$6.25	$10.00
Non-Local Public Match -3	$2.00	$5.00	$7.50	$12.50	$20.00
User Fees -4	$3.44	$8.59	$12.89	$21.48	$34.36
Annual Cash Flow	$8.69	$21.72	$32.57	$54.29	$86.86

Notes:
1. Assume $2.50/SF of new development, 50% contributed to project
2. Assume annual assessment of $1.00/SF new development, $0.50/SF existing development; incorporates on-site and off-site improvement savings and benefits from faster lease-up and higher rental income
3. Assume match of private assessment proceeds from state, federal and/or county sources for savings in road outlays, new tax receipts and other benefits
4. Assume user fees charged for regional transport services or parking facilities at $3.00/day for each avoided auto for 250 days/year, but people mover charges no fee
5. Assume 3.055 cars/1,000 SF base case

- Will the locality share the tax increment?
- What is the new taxable square footage?
- What is the tax rate?
- What share of the tax increment will the locality contribute?

Property tax is an important revenue source because it is readily bondable and can be leveraged to generate capital funding up front.

To organize the revenue sources presented and demonstrate the framework's adaptability to individual cases, several financing scenarios have been devised using the following assumptions:

Item	*Amount*
Scale of activity center	10.0 million ft^2
Gross level of auto reduction	40 percent over base case
New growth permitted by auto reduction	4.0 million ft^2
Base case automobiles	3.055 cars per 1,000 ft^2
Net automobiles reduced after new growth	4,887 cars
Avoided automobiles	17,105 cars
Cost per square foot of development rights	\$35.00/ft^2
Percentage of new density value actually realized	65 percent
Property tax rate	\$2.00/ft^2
Percentage of property tax increment available	50 percent
Assessment rates—	
Existing development	\$0.75/ft^2
New development	\$1.25/ft^2
Nonlocal public match	Equal to assessment proceeds
Capitalization rate for revenues	10 percent
User fees	\$3.00 per avoided automobile per commuting day (250/year)

Note that although the 50 percent tax increment split is maintained in the assumptions, the tax rate has dropped to \$2.00/ft^2.

Financing Scenario A capitalizes value from new development rights and the property tax revenue stream. The balance of the cash flows are used to support annual operating costs and lease expenses. It is important to consider that the capital category of the scenarios could represent the aggregation of numerous, smaller-scale projects implemented over time, as well as the funding potential to undertake a single, larger-scale project all at once.

Financing of Scenario A using leveraged property tax would consist of the following elements:

Item	*Amount (\$ millions)*
Capital	
Sale of new development density	91.0
Leverage incremental property tax	40.0
Subtotal capital	131.0
Annual revenues for operating and lease costs	
Assessment proceeds	
Existing development	7.5
New development	5.0
Nonlocal public match	12.5
User fees	12.8
Subtotal, annual revenues	37.8

Special Assessments

Special assessments are assumed to be levied on new and existing development as a means to translate various tangible and intangible benefits into dollar terms. The benefits include

- Reduction in onsite development costs—primarily internal roads, parking, and site preparation;
- Reduction in offsite development costs—primarily road improvements to facilitate access to the subject property, proffers, impact fees, etc.;
- Faster lease-up because of access amenity and improved project image; and
- Higher rent flow from new retail opportunities and greater land values from better access.

Onsite development costs vary for every property; however, the need to provide internal road systems and surface or structured parking always consumes both land and dollars. Reducing onsite costs is a source of value that can be quantified on a site-specific basis and negotiated with developers on the basis of before-and-after comparisons. A caution note is entered here because institutional issues that are explored in the next section are raised by this assumption.

Offsite improvement is another instance where costs can be quantified on a project-by-project basis. In some cases, predetermined impact fees may be assessed against new projects, whereas in others negotiated proffers may be exacted in exchange for development approvals.

Allowing investments in the distribution system to offset impact fees or proffers reallocates outlays developers are already required to make.

For example, Anne Arundel County, Maryland, has imposed a schedule of transportation impact fees that will drift up to over \$1.00/ft^2 for some office projects, whereas San Francisco levies a \$5.00/ft^2 transportation impact fee. The fees are generally financed over time, either by the jurisdiction or as a land (or development) cost that is folded into a project's permanent financing.

A distinction must be drawn between new and existing development (including instances where property owners' development entitlements have vested even though construction may not be underway or completed) because existing projects may have paid offsite fees and made onsite investments. In these cases, developers, lenders, and tenants must be protected from assessment for benefits already purchased.

Table 1 incorporates the assumption that existing projects are assessed at half the rate of new ones, whereas Table 2 includes a 50¢ differential between the two assessment categories. The more intangible benefits of higher property value accruing from greater accessibility, improved rents, and opportunities for income from new uses accruing to existing development sites are thus separated from the more tangible benefits to new development.

Nonlocal Public Match

A public-private partnership implies that the public sector is prepared to reinvest some of the benefits it receives from the program. Thus far in the scenario, the local jurisdiction is

TABLE 2 ASSUMPTIONS FOR FINANCING SCENARIOS

Scale of activity center	10.0	million square feet
Gross level of auto reduction	40%	over base case
New growth permitted by auto reduction	4.0	million square feet
Base case autos	3.055	cars/1,000 square feet
Net autos reduced after new growth	4,887	cars
Avoided autos	17,105	cars
Cost/square foot development rights	$35.00	per square foot
Percentage of "new" density value actually realized	65%	
Property tax rate	$2.00	per square foot
Percentage of property tax increment available	50%	
Assessment rates -		
Existing development	$0.75	per square foot
New development	$1.25	per square foot
Non-local public match	Equal	to assessment proceeds
Capitalization rate for revenues	10%	
User Fees	$3.00	per avoided auto per commuting day (250/year)

assumed to contribute one-half of its property tax increment—a substantial commitment.

Other benefits at the county, state, and federal levels also may be identified—perhaps through enhanced income or sales tax revenues from greater economic activity, job creation, or other means. Investment in regional feeder modes and the distribution system may offset the need for additional highway construction and maintenance. How to calculate and incorporate these benefits into the project through federal, state, or county contributions could be the subject of another paper.

For the purpose of this simplified analysis, a public contribution equivalent to the proceeds of the private sector special assessment is assumed both in Tables 1 and 2.

Financing Scenario A shows the nonlocal public match as an annual revenue stream, whereas Scenario B capitalizes the equivalent revenue stream into an up-front grant.

Although incremental property taxes are shifted in Scenario B to supporting annual operating costs, there is no reason that all, or a portion of, these funds could not be leveraged in addition to the nonlocal public match.

Financing of Scenario B by leveraged nonlocal public match would consist of the following elements:

Item	*Amount ($ million)*
Capital	
Sale of new development density	91.0
Leverage nonlocal public match	125.0
Subtotal, capital	216.0
Annual revenues for operating and lease costs	
Assessment proceeds	
Existing development	7.5
New development	5.0
Incremental property tax	4.0
User fees	12.8
Subtotal, annual revenues	29.3

User Fees

In this application, the people mover is perceived exactly as an elevator and thus charges no fare.

However, fees may be paid at park-and-ride lots or garages; and regional connector services, such as express buses, vans, rail systems, or shared-ride arrangements, can charge fares. These receipts are estimated in Tables 1 and 2 as $3.00 per commuting day (250 days per year) per avoided automobile. More refined estimates based on the planned mix of regional transport services, anticipated noncommute usage, and vehicle occupancies of the avoided automobile trips can be derived on a case-by-case basis. Reflecting the lack of certainty with which user fees can be projected, it is not possible for such revenues to be capitalized.

PRACTICAL AND INSTITUTIONAL ISSUES

Attempting to fit even the simplified set of pieces just described into place sounds complex enough, but the job is hardly complete. There are other issues that must be confronted if the preceding is to be more than just an academic exercise.

First is the creation and sale of new development density. This concept presumes that an activity center has a defined perimeter and that the local government has established a maximum growth limit within the designated area. In fact, the real world does not operate this way.

Not only are there often blurred boundaries to activity centers, in many cases the existing zoning within designated commercial areas provides for many times more development than either the market or any infrastructure system could absorb. In these cases, zoning by itself does not limit developers from obtaining entitlements, and environmental impact and growth management processes are used as regulators.

The result is that downzoning, which is very difficult to achieve, may have to occur; or new zoning overlay districts may have to be created that impose special requirements on future development. The solutions will have to be negotiated with property owners and will vary depending on local law and market conditions.

Second is the timing and sale of new development density. Will existing projects be able to purchase development rights to place additional buildings on vacant land or surface parking? Will the new rights be held in a bank available for lease or purchase? How will prices be set and will they vary over time? Will property owners be able to transfer the rights among themselves? How will timing of the development rights sales compare with the circulation system's construction requirements and operating outlays?

Models and precedents for addressing these issues can be found in other fields, particularly in water and sewer system finance. The ability to build circulation networks incrementally will be an important factor in addressing timing concerns.

Third, the impact of any new procedures or financial requirements on existing projects must be considered in light of the developer's obligations to lenders and tenants. For example, if a locality reduces parking requirements in an activity center to one space per 1,000 ft^2 of development, a developer may still have to secure more parking to attract tenants and convince lenders to provide financing.

In instances where projects are built out and plans are drawn to relocate existing parking to peripheral areas, or surface parking is used for additional development, the terms of existing leases and mortgages will have to be renegotiated. Similarly, who pays assessment fees—the tenant or the developer—will depend on lease terms.

Finally, any attempt to redefine transportation services in an activity center will create instability in the market for development. Involving the private sector early and making sure requirements that emerge from the planning process allow developers to obtain entitlements in an atmosphere of greater, rather than reduced, certainty will improve chances for success.

PROFILE OF LIKELY CANDIDATES

The most likely candidates for people mover systems will be larger activity centers in strong markets, with high land values. These areas have developed credibility with lenders and tenants, and must become more urbanized if future expansion is to occur.

Further road construction is likely to be physically impossible, uneconomic, or environmentally unacceptable. Traffic congestion already may be at the point where it is limiting growth, either by resistance of tenants to lease space, or through an artificial lid on development—such as the adequate-facilities moratorium imposed in Rockville, Md.

Public agencies in hot areas may be enticed to consider creating new development rights if artificial constraints on construction are chasing growth into neighboring localities. Depending on where unplanned commercial activity is occurring in the region, road problems may be exacerbated by through traffic to other jurisdictions, who are at least deriving the benefit of additional taxes.

In weak markets such as Dallas, boosting permitted densities may be ignored by a stagnant market, or could depress land prices beginning to recover from an oversupply of development. New assessments cannot be passed on to tenants and result in lower net rents. Lenders (or federal deposit insurers, as the case may be) need to be convinced that throwing additional dollars for infrastructure on top of current losses will hasten the day of positive cash flow—a tough selling job.

Building infrastructure as a pump priming technique, or as a means to accelerate absorption of large volumes of vacant space, involves a degree of risk that only the public sector can assume.

CONCLUSION

Application of people mover technology in suburban activity centers can be financially feasible if part of a regional traffic mitigation strategy and system costs are related to economic benefits.

To address existing conditions in larger, well-established activity centers—those with the greatest economic potential for people movers—a mix of building linkage techniques and, probably, people mover technologies may be appropriate. The capability for incremental implementation will be a critical success factor.

Reversing the current approach to feasibility analysis by first establishing the magnitude of potential benefits and then designing circulation systems within a cost constraint would be timely.

Future research should examine techniques to reduce construction costs and aesthetic concerns; options for private design and construction of system elements; and consideration of a joint effort with developers, local planning officials, and institutional lenders to recommend alternative solutions to foreseeable implementation concerns.

A promising line of investigation is suggested by William J. Head et al. (*1*).

REFERENCE

1. W. J. Head et al. *Feasibility of Using Composite Materials for Transit Guideway Systems.* USDOT/UMTA University Research and Training Program Report WV-11-0003-7, West Virginia University, Morgantown, April 1985.

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