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Guidelines and Standards for the Planning, Design, and Operation of Bus Park-and-Ride Facilities

JOSEPH J. MATHER

A set of guidelines and standards for the planning, design, and operation of express bus park-and-ride facilities are presented. Their purpose is to ensure that facility development activities will fulfill local needs while supporting efficient bus transit operations. The guidelines and standards have been developed for and are being applied to a statewide park-and-ride facility development program being undertaken by the New Jersey Transit Corporation (NJ TRANSIT). The goal of NJ TRANSIT's park-and-ride program is to develop within each bus service corridor a network of properly sized parking facilities located to support efficient bus operations and convenient user access. Parking needs at comparatively low-demand boarding points are addressed through joint-use development, while higher-demand boarding points are served with exclusive-use investments. Facility design standards ensure that park-and-ride facilities are safe, convenient, and easy to maintain. Exclusive-use facilities are designed to provide 15-20 years of low-maintenance service. NJ TRANSIT's park-and-ride program is a capital program and does not provide funds for facility operation. Operating costs are typically recouped through user fees. In cases where NJ TRANSIT does not operate a park-and-ride facility, operating oversight is maintained through a 15- to 20-year contract with the facility operator. This contract provides the user with a well-maintained facility at a reasonable cost.

Park-and-ride facilities improve the transportation system in many ways. Commuters benefit from reduced trip costs and avoid the frustration and hazards of automobile use on congested roadways. Passenger consolidation at park-and-ride facilities benefits transit operators by increasing vehicle loadings, extending the reach of service into low-density areas, and reducing the need for costly collector and distributor route segments. The transportation system as a whole benefits from reduced energy consumption, pollutant emissions, and roadway expansion and maintenance needs.

Park-and-ride activity in New Jersey is well established, widespread, and multipurpose. A statewide inventory of park-and-ride facilities performed in 1980 identified 16 497 stalls at 151 formal facilities and 8681 stalls at 59 informal facilities. These 210 facilities range in size from 20 to 1600 stalls and support passenger transfers to private ridesharing, commuter rail, and express and local bus services.

The benefits generated by a given park-and-ride facility vary with facility location and use characteristics. Facilities located at the central business district (CBD) periphery reduce downtown automobile use but do not reduce CBD approach traffic volumes or extend the reach of efficient transit services. Remote transit park-and-ride facilities can provide the full range of user, operator, and system benefits but only if the level of passenger consolidation is sufficient to support convenient and efficient transit service. Carpool-oriented facilities generate user benefits but have a more limited impact on the transportation system and are sometimes detrimental to transit services. Park-and-ride facilities can be designed and located to serve any of these various commuter market segments and, therefore, to achieve distinct transportation system objectives.

The New Jersey Transit Corporation (NJ TRANSIT) has recognized the potential for park-and-ride facility development to concentrate commuter demand to the benefit of its bus transit system and has embarked on a seven-year bus park-and-ride development program. The goal of this program is to construct a network of park-and-ride facilities that will improve bus transit operating performance and expand the bus transit commuter market share. At the conclusion of the first year of the program, $2.1 million will have been expended to construct 1895 stalls at eight new facilities, to renovate 1427 stalls at four existing facilities, and to support joint-use park-and-ride activity with shelters, signs, and modest capital improvements.

With the opportunity to create a network of operations supportive of park-and-ride facilities comes the danger that poorly planned development will fragment commutersheds and eliminate the sought-after benefits of passenger consolidation. NJ TRANSIT has declined to participate in three facility proposals because of potential intratransit competition. The following guidelines and standards have been drafted to guide facility development toward the intended goals.

Because a variety of local conditions stimulate park-and-ride activity in New Jersey, other transportation management agencies may find these guidelines and standards useful. The guidelines and standards have been effective in aligning public demands for facility development with transit system operating requirements. (NJ TRANSIT will be pleased to share more specific planning, engineering, and legal information gained in program implementation. Please direct all inquiries to the Director of Planning, NJ TRANSIT, P.O. Box 10009, Newark, New Jersey 07101.)

ORIENTATION

Park-and-ride development policy is oriented toward improving transit operating performance, increasing transit ridership, and reducing highway congestion. Although NJ TRANSIT can exert the greatest influence on park-and-ride network effectiveness through investments in comparatively large and permanent facilities, smaller exclusive-use and joint-use facilities also contribute to a balanced and effective network. Regardless of size, all park-and-ride facilities should achieve the following objectives:

1. Should provide adequate parking capacity to meet existing and future needs;
2. Should be permanent, durable, resistant to abuse, and easy to maintain;
3. Should provide an attractive, visible, high-quality environment that meets modern standards of comfort and safety;
4. Should be recognized as elements of a park-and-ride network, provide an extensive display of transit system information, and be identified for ease of location;
5. Should be designed to encourage commuter bus access by walking, bicycle, automobile drop off, and other shared-ride methods in addition to automobile driver access; and
6. Must be compatible with surrounding land uses and community needs and activities.

The size and type of park-and-ride facility appropriate to a specific site is primarily determined by the level of park-and-ride demand. In addition to the number of parking stalls, demand levels will determine maintenance, security, and amenity requirements; the extent and intricacy of the internal circulation system; and the need to insulate the facility from adjoining land uses. The following guidelines and standards have been devised to reflect varying levels of facility use.

NJ TRANSIT supports the development of a rationally structured park-and-ride network through capital assistance for site acquisition and facility design and construction. In order to best use the limited capital resources available, NJ TRANSIT actively seeks the participation of both public and private organizations in facility development and operation. Such participation is sought from organizations whose employees or constituents will benefit from the facility as well as from those organizations that may be able to make use of a facility for purposes other than transportation. Examples of such involvement to date include private bus carriers, municipalities, and shopping centers. Although there is no matching requirement, funding priority will be given to those proposals that, otherwise fully justified, are supported with capital contributions from other sources.

On the completion of facility construction, all NJ TRANSIT-funded improvements become the property of the site owner. The public interest in the park-and-ride facility is preserved through a long-term agreement that grants NJ TRANSIT operating oversight. NJ TRANSIT does not have the resources to operate and maintain park-and-ride facilities and cannot provide funds for facility operation and maintenance.

PARK-AND-RIDE FACILITY LOCATION AND DESIGN

Location Criteria

Park-and-ride facilities improve transit service and operating performance by focusing demand near high-capacity roadway interchanges. Increased passenger loads collected over fewer boarding points can justify the levels of express service required to attract commuters, thereby making them willing to drive to reach the transit service. To intercept automobile trips and facilitate modal transfer with minimal delay, facilities must be properly located within the express bus commutershed, the regional highway system, and the transit network.

Park-and-ride facilities must be located within unique commutersheds to avoid fragmenting the area's ridership; competing facilities reduce the overall level of transit services provided. Average access distances are inversely proportional to the distance to the destination terminal, ranging from a high of 19.3 miles at distances of less than 1 mile to a low of 2.5 miles at distances more than 40 miles, and averaging across facilities at 3-6 miles. Currently, facility market areas are determined by using passenger origin data collected during a 1981 ridership survey performed by the Port Authority of New York and New Jersey. Although not yet fully processed, the survey data indicate that facilities developed beyond the CBD periphery should be located approximately 4-5 miles apart. This very general guideline should be applied with site-specific factors, including the locations of alternative transit facilities and the planned frequency of express bus service.

Although larger facilities tend to support improved transit services, the consolidation of boarding points over a wide area will also tend to increase automobile access travel distances. The intent of this program is to develop facilities that balance the positive aspects of passenger consolidation with the negative consequences of automobile travel.

Park-and-ride facilities must be located to intercept automobile trips along normal commuting paths. Circuitous access paths can increase overall trip times to unacceptable levels. Therefore, facilities will be most effective when located near high-capacity roadway interchanges. Appropriate measures must also be taken to avoid traffic delays when entering or exiting a facility and to ensure that adjoining land uses are not adversely impacted. The roadway and land use types found near highway interchanges are typically conducive to remedial treatments as needed.

Park-and-ride facilities must be directly served by express bus services to minimize excessive walking distances. Experiences at railroad station parking facilities indicate that commuters consider a 400-ft walk to the boarding point acceptable, but resist walking more than 1500 ft. Facility location must provide direct express bus access to nearby high-capacity roadways. Although new park-and-ride facilities of comparatively small size must be served by existing bus routes, service modifications will be considered if needed to exploit available development sites for larger facilities.

Size Criteria

Park-and-ride facilities identify the presence and structure of commuter bus services. In addition to the fulfillment of current needs, facilities should be sized to stimulate and serve ridership growth. Capacity requirements are estimated from the projected year-2000 population level within the facility market area. Commuter bus use can range up to 25 percent of market area population, and access by park-and-ride can capture up to 70 percent of boarding passengers. Data are currently being evaluated to further quantify the relation between market area characteristics and park-and-ride demand. Park-and-ride facilities should be constructed or expanded to service year-2000 estimated parking demand by using a 95 percent occupancy design standard.

NJ TRANSIT-funded park-and-ride facilities are intended to be long-term investments in the transportation system. Development sites should currently evidence the minimum level of park-and-ride activity needed to support frequent bus service into the foreseeable future. Boarding points with an estimated year-2000 demand of less than 100 daily boarding automobile drivers are inadequate in themselves to support this level of service and should not be considered for exclusive-use facility development.

In general, park-and-ride facilities improve transit service and reduce operating costs by concentrating demand. The larger the facility, the greater its impact on service quality and cost. As an example, a corridor that consists of four park-and-ride boarding points can support 10-min peak period headways if each facility serves approximately 150-175 automobile drivers.

Joint-use facilities offer an opportunity to serve commuters at low-demand boarding points. Such facilities typically occupy vacant or excess parking capacity at retailing centers. NJ TRANSIT will pursue a formal joint-use agreement with the owners of such properties and will provide shelters, signs, and minor capital improvements as needed. These agreements have been successful in preserving the public use of private facilities while maintaining the commercial benefits and community goodwill derived by the site owner. Improvements to a joint-use facility should reflect the temporary nature of its public use and will be limited to portable or very low-cost capital improvements. NJ TRANSIT does not have the resources to maintain joint- or exclusive-use facilities and does not have the authority to pay fees for the use of parking stalls.

As commuter parking demand grows, commuter activity may begin to conflict with the host's normal business operations. Joint-use facilities that serve more than 100 boarding automobile drivers daily evidence sufficient demand to justify an exclusive-use facility and should be viewed as a medium- to short-range solution to commuter parking needs.

Design

Park-and-ride facilities should be designed to provide the maximum quantity of parking consistent with safe and efficient operations. The most effective facility design is determined by lot size and shape and will be site specific. The following guidelines present the preferred design orientation. Facility design shall conform with the current Transportation and Traffic Engineering Handbook of ITE (1).

The boarding and discharge area will preferably be located along the perimeter of the parking area to avoid congestion and delays. Larger facilities that require a central boarding area location to reduce walking distances will be designed to limit feeder mode interference with line-haul operations. Boarding and discharge areas shall be easy to identify and shall be signed.

Perimeter boarding areas shall use raised platforms for definition and safety. Platforms will ideally be 10-12 ft wide by 60 ft long and constructed with a concrete or blacktop surface. A hard surface edge designed to act as a curb shall be provided at the loading side of the platform. Centrally located boarding areas that use raised platforms should be designed to reduce snow removal and other maintenance difficulties. Passenger shelter needs at boarding platforms are discussed under the section on Shelter and Passenger Amenities.

The parking area shall be designed as double-loaded 90° bays whenever possible. Circulating roadways shall provide for two-way traffic. One-way circulation, single-loaded bays, and parallel and angle parking shall be used only as required by site-specific constraints. The average walking distance between parking stalls and the nearest boarding area should be no more than 400 ft, with the maximum walking distance in the 1500-ft range.

Parking stalls shall be striped whenever possible, and shall conform with the design standards of Parking Principles, an HRB special report (2). Compact car parking stalls shall be a minimum 7.5 ft wide and 15 ft long within a total bay width of 50 ft for double-loaded perpendicular parking.

Full-sized car parking stalls shall be a minimum 8.5 ft wide and 18.5 ft long within a total bay width of 63 ft for double-loaded perpendicular parking. Parallel parking stalls shall be 8 ft wide and 22 ft long. The division of parking capacity between compact and full-sized stalls shall be evaluated within the context of site-specific constraints and observed use patterns.

Parking stalls for individuals with physical handicaps shall be 12 ft wide and 18 ft long with an unobstructed access to walkways and boarding areas suitable for wheeling and walking. A minimum of two handicapped stalls or one handicapped stall per 100 parking spaces shall be provided, whichever is greater. Parking stalls for the handicapped shall be reserved for the exclusive use of the handicapped and shall be well marked, proximate to the boarding area, and otherwise conform with the New Jersey barrier-free design regulations (3).

Space for bicycle parking shall be provided at the facility boarding area or other supervised location on a well-drained hard surface with overhead protection, if possible. Bicycle parking demand will be estimated at the time of facility design through surveys or informed local knowledge. Bicycle racks should be provided for short-term and infrequent users, while bicycle lockers should be provided for regular users on a lease basis only. Because lockers should be leased, bicycle lockers can be procured incrementally as demand warrants.

Construction Standards

Construction standards are formulated to ensure that park-and-ride facilities will be durable, easy to maintain, and continuously available during periods of inclement weather. Because the level of use is the primary determinant of facility design, maintenance requirements and potential for long-term use, construction methods, and materials should become progressively oriented toward greater durability with increasing facility size.

Proper surface drainage is attained through careful grading. A minimum 1 percent slope and a maximum 3 percent longitudinal and 6 percent cross slope are desirable. Sharply sloping sections should not be used for parking, but may be developed to provide space definition, mode separation, or screening.

Parking facilities of more than 200 parking spaces shall use a minimum 2-in fine aggregate base coat, a 2-in bituminous concrete stabilized base, and a 6-in gravel base. Facilities with less than 200 parking spaces may employ an 8- to 12-in gravel base only, depending on soil conditions at the site.

Concrete, granite, or bituminous concrete curbs will be provided at the edges of parking areas where required for drainage or vehicle containment. Guardrails will be used instead of concrete wheel stops where needed to limit vehicle overhang or incursion. All curbs shall be ramped where appropriate along pedestrian and bicycle pathways. Curbs or barriers between stalls and bays should be avoided because they make efficient snow removal impossible.

All park-and-ride facilities shall be illuminated to a minimum two to three maintained footcandles throughout. Boarding areas shall be illuminated to a level of 10 footcandles. Facility illumination shall provide a light uniformity ratio not exceeding 6:1 and shall otherwise be in conformance with the current ITE Transportation and Traffic Engineering Handbook. A time clock shall be used to activate and extinguish facility lighting before and after the normal period of bus service. The time clock shall be governed by a light-sensor override to eliminate resetting for seasonal sunrise and sunset variation.

Site Access and Circulation

Park-and-ride facilities shall be designed to provide safe and convenient access with minimum delay. Vehicular access points should be a minimum 150 ft apart and conform with current AASHTO highway design standards when connecting with the public right-of-way. The facility name and entrance location will be clearly identified, as will all warnings and instructions necessary for the safe and expeditious flow of traffic.

Pedestrian walkways shall be provided to channel pedestrian movement as required for safety and operational efficiency. Painted crosswalks, rather than grade-separated walkways, shall be used to channel pedestrians across open parking areas. Pedestrian circulation paths should provide direct access to public walkways and should follow pedestrian travel desire lines irregardless of planned automobile access routes.

Walkways shall have a typical width of 5 ft to permit ease of passage for two pedestrians. Walkways shall be continuously paved and use ramped curbs in order to smooth edge discontinuities. All walkways shall be designed for use by the transportation handicapped and shall conform with the New Jersey barrier-free design regulations.

Provisions for kiss-and-ride circulation shall be made at all park-and-ride facilities and separated from parking and bus movement to the degree necessary to ensure the expeditious flow of traffic. Drop-off and pick-up areas shall include short-term automobile waiting spaces. Waiting-space requirements are directly proportional to the level of kiss-and-ride activity and inversely proportional to the frequency of bus service. Waiting-space requirements are, therefore, site specific and should be evaluated within the context of the facility and area under consideration.

Shelter and Passenger Amenities

Passenger amenities promote transit use through the provision of comfortable, safe, and attractive services and facilities. Passenger amenities are necessary and cost-effective transit improvements.

Park-and-ride facilities are most heavily used during the peak periods when they receive frequent service. Ticket offices and station buildings are not required for the efficient operation of a park-and-ride facility and may be provided only at the full expense of the facility or service operator. Passenger shelter needs can be adequately fulfilled through the provision of bus shelters.

Shelter needs are determined by the number of passengers boarding each bus and, to a lesser extent, by passenger arrival patterns. As a guideline, shelter should be provided to accommodate approximately 85 percent of the highest boarding load at a given site. The standard bus shelter used by NJ TRANSIT accommodates 13 people. Site illuminations shall provide the shelter area with a minimum 10 maintained footcandles of illumination, and shelter maintenance is the responsibility of the facility operator.

Public telephones enable commuters to arrange for private automobile, taxi, or paratransit pick-up services. At least one public telephone shall be available near the automobile drop-off and pick-up area but must not obstruct passenger or vehicle movement or obscure sight lines. The provision of public telephones shall be pursued during facility construction.

Trash receptacles and ashtrays will be placed near all boarding and discharge areas and within the parking area as practical. Anchored vending machines or mailboxes may be provided at the discretion and responsibility of the facility operator.

Planting, Screening, and Landscaping

Planting and landscape materials can be used to provide a suitable facility setting, provide screening from adjacent properties, shape large parking areas, stabilize slopes and embankments, and keep unpaved horizontal surfaces in good condition.

Six- to eight-foot evergreens provide effective screening to block view and headlight glare from adjacent areas. Ten-foot-wide screening areas are generally desirable. Caliper deciduous trees 2.5 ft high are appropriate for general planting. Vertical screens or fences may be used to protect the privacy of neighboring parcels.

Low-maintenance landscape materials should be used to cover unpaved horizontal surfaces. Brick or stone set in sand is recommended for unpaved surfaces of less than 75 ft^2. Low-maintenance ground covers used with wood-chip mulch are desirable for areas of between 75 and 200 ft^2, and grass is appropriate for areas greater than 200 ft^2 if used with the concurrence of the facility operator.

Information Systems

Information systems shall be provided to identify public transportation services and to direct their safe and efficient use. An effective information system is an essential element of a public transportation facility and should be considered during the early phases of facility development. All information system elements shall conform with specifications set forth in NJ TRANSIT's Graphics Standards Manual.

A facility information system will identify and direct access to the facility, direct traffic within the facility, and locate and instruct the use of facility services, service areas, and equipment. On-site sign placement should be coordinated with the facility illumination system to avoid the need for additional lighting fixtures. The system should include trailblazer signs; facility identification signs; direction and regulatory signs to identify parking, boarding, and waiting areas; and a map of the regional (corridor) transit system, available line-haul and feeder service routing, boarding points, and operating schedules.

Major approach routes to all park-and-ride facilities shall be identified with trailblazer signs. In general, trailblazers will be placed at intersections of all arterial roadways within 3 miles upstream and 1 mile downstream of the facility and at 0.5-mile intervals along the approach route. Special bike route access signs may be appropriate, depending on local conditions.

MAINTENANCE AND OPERATION GUIDELINES

Operating Agreement Guidelines

At the completion of construction, all NJ TRANSIT-funded improvements become the property of the site owner. The public interest in the park-and-ride facility is protected by NJ TRANSIT through an operating agreement with the facility owner or management representative. Operating agreements ensure that the facility will function for the benefit of the commuter public and the public transportation system as a whole, and that the facility shall be properly maintained.

The term of the operating agreement specifies the period of time a facility will be available for public transportation use under NJ TRANSIT operating oversight. As a policy guideline, a 20-year term has been determined to reflect the useful life of capital improvements and the period of time public need for a facility can be reasonably forecast.

Terms of less than 20 years may be negotiated if NJ TRANSIT-funded improvements are inexpensive or portable or if the cost of the NJ TRANSIT-funded improvements can be recovered through operating revenue. Terms of less than 20 years shall be negotiated only to the extent that the level of user charges does not discourage facility use, that facility quality is not compromised, and that the facility will be available during the anticipated period of need. The principle purpose of park-and-ride facilities is to encourage transit ridership and to support transit operations.

Facility owners may withdraw from an operating agreement on 90 days notice by compensating NJ TRANSIT for the depreciated value of the improvements it has funded. The value of NJ TRANSIT-funded improvements shall be depreciated on a straight-line basis over the term of the operating agreement.

Facility Use Restrictions

Park-and-ride facilities developed with state and/or federal funds will be available to all commuters and transit operators on a nondiscriminating basis. Facility use shall not be restricted to residents of any particular community, and differential parking fees may not be used to favor specific user groups.

Operating Cost Responsibility

The facility operator is responsible for all costs necessary for the safe operation and maintenance of the facility, including security and utility costs and taxes. The primary source of operating cost recovery is likely to be parking fee revenues.

Parking facilities are to be maintained for the benefit and service of the commuter public. Parking fees will be based on the total cost of maintaining and operating the facility less other fees and revenues, plus a 10 percent contingency fund. In an instance where federal monies are used to construct or improve parking facilities, federal guidelines and regulations shall govern.

The operator shall include within its annual operating budget an analysis of how the fee structure was determined for that coming year. Parking fee schedules for the first year of operation shall be established in consultation with NJ TRANSIT by using cost data from selected cases. Fee schedules for subsequent years shall be based on prior operating and maintenance costs. The method of fee collection shall not reduce the attractiveness of the facility to infrequent and off-peak users.

All user fees are subject to NJ TRANSIT approval, and NJ TRANSIT explicitly reserves the right to limit the fee to a level that may not recover total operating and maintenance costs. Such an action may be taken only if the proposed user fee will significantly inhibit facility use. Site-specific conditions may enable or require the operator to set fees above those mandated by the above procedures and considerations. In these instances, the operator shall submit a written justification for the proposed fee schedule to NJ TRANSIT for approval.

Marketing

Effective marketing can both increase the level of park-and-ride facility use and hasten the rate of user growth. Both outcomes are particularly beneficial to new facilities, which require immediate revenue to meet operating expenses. Over the longer term, park-and-ride facilities become a useful focus for promotion and information campaigns that benefit the facility as well as its transit services.

NJ TRANSIT recognizes the importance of marketing in realizing full facility potential and will fund an initial promotion and information effort within the facility design and construction budget. The type and extent of the initial effort will be determined by NJ TRANSIT's Department of Marketing Services during the facility design process. Subsequent marketing activities needed either to stimulate additional facility demand or to promote the area's transit services shall be funded through the operating fund contingency account, as jointly directed by the Department of Marketing Services and the facility operator.

Advertising revenues are an additional source of income to defray operating expenses. NJ TRANSIT uses an independent advertising agency to manage its advertising resources and, with the approval of the site owner, will direct this agency to evaluate the feasibility of on-site advertising. All advertising on NJ TRANSIT-funded facilities shall be managed and maintained by the advertising agency currently under contract to NJ TRANSIT, and all graphics and advertising shall be approved by NJ TRANSIT prior to installation. Advertising revenues shall be shared among NJ TRANSIT, the site owner, and/or the facility operator according to an agreement negotiated on a case-by-case basis.

Excess Revenues

In the event that facility revenues and fees exceed those required for operation and maintenance, excess funds will first be used for required facility improvements as determined jointly by NJ TRANSIT and the operator. If required improvements are projected within a five-year period, excess revenues and contingency funds may be accumulated to finance or provide matching funds for required improvements. If the operator and NJ TRANSIT agree that no improvements are required, excess revenues shall next be used to reduce parking fees or to finance other public transportation services directly related to the continued use of the facility on NJ TRANSIT's prior written approval.

Indemnification and Insurance

Indemnification

The facility operator shall defend, indemnify, protect, and save harmless NJ TRANSIT, its agents, officials, employees, and servants against all claims that occur as a result of incidents on the facility, with the exception of those incidents directly related to bus transit operations. The facility operator shall make no claim against NJ TRANSIT for or on account of any loss or damage whatsoever.

Insurance

The facility operator shall provide public liability insurance covering the park-and-ride facility with minimum limits of $2 000 000 per person and per incident. The facility operator's policy shall cover all incidents that occur on the facility with the exception of those accidents directly related to bus transit operations. NJ TRANSIT shall be designated a named insured on all insurance coverage that is the responsibility of the facility operator and shall have the right to require the facility operator to add other named insureds as circumstances require.

The maintenance of insurance shall not release the facility operator from any liability when such liability for injury, death, and/or property damage is either within deductible policy limits or is greater than the insurance coverage.

Maintenance Standards

Facility maintenance is required to provide a clean, comfortable, and safe environment and to minimize reconstruction needs and otherwise prolong facility life. The facility operator is responsible for all regular maintenance activities required to keep the facility in a clean and safe condition. Regular maintenance requirements will include, as a minimum on an as-needed basis, the following:

1. Sweeping and cleaning of shelters, platforms, parking areas, and access roadways, and the removal of litter and rubbish;
2. Grounds keeping, including weed control, the cutting of grass, and other landscaping activities;

3. Ice control and snow removal; and
4. Oversight of licensees responsible for the maintenance of on-site facilities and equipment (e.g., vending machine operators).

Although park-and-ride facilities are more or less permanent, specific elements require periodic repairs or replacement for uninterrupted operation. The facility operator is responsible for all periodic maintenance activities necessary for continuous structural integrity and aesthetic appearance. Periodic maintenance requirements are dependent on facility design, construction, and use and must be identified to permit the accumulation of needed reserve funds and construction scheduling. Examples of periodic maintenance needs include surface repairs and patching, replacement of luminaires, and striping of crosswalks and parking stalls.

The facility operator shall perform all minor structural, electrical, lighting fixture, pavement, and fee-collection equipment repairs promptly as needed. The operator shall also promptly remove graffiti and repair other damage due to vandalism. Major repairs, improvements, or expansions of existing facilities will be undertaken by the facility owner as contractor under cost reimbursement and performance agreements to be negotiated with NJ TRANSIT on a case-by-case basis. Pavement resurfacing is an example of a major repair item. Expenditures for major repairs, improvements, or expansions will typically result in an extension of the operating agreement.

Financial Reports

If the operator receives revenues from the use of the facility, it shall submit an annual operating budget 90 days prior to the start of each fiscal year and an annual financial report 90 days following the close of the fiscal year. The financial report shall be certified as accurate by a certified public accountant. Revenues and expenses related to the park-and-ride facility shall not be aggregated with other revenues and expenses and shall be maintained and reported in a separate account.

The annual operating budget submission shall contain line items for all projected operating and maintenance expenditures. NJ TRANSIT may require budget line item changes based on its review of the annual operating budget. NJ TRANSIT will submit changes prior to the end of the fiscal year.

In the event that no revenues are received by the operator or are not contemplated being received, the operator shall submit in writing a statement to this effect.

In determining the budget, a 10 percent contingency fund should be reserved. The transfer of contingency funds and excess revenues to other line items related to facility operation and maintenance shall be subject to NJ TRANSIT's prior written approval.

ACKNOWLEDGEMENT

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Estimating the Effects of Residential Joint-Development Policies on Rail Transit Ridership

JEROME M. LUTIN AND BERNARD P. MARKOWICZ

A study that examines the impact of residential growth management strategies on transit ridership on a proposed rail transit corridor is presented. An interactive corridor sketch-planning model was developed to replicate various residential density patterns in the corridor and estimate transit patronage for work trips. The model also estimates patronage for transit access modes, including walk-and-ride, park-and-ride, kiss-and-ride, and feeder bus. Automobile drive-alone, carpool, and vehicle miles of travel (VMT) statistics for work trips are also reported. The model allows the planner to test combinations of policies to concentrate growth in high-rise buildings, create clusters of medium-rise housing, and restrain growth in exurban portions of the corridor. The transit ridership impacts of these policies are compared with an unmanage growth base case. It was found that through stringent land use controls, rail transit modal split could be increased by almost 16 percent over the base case, with a reduction in overall VMT for central business district bound work trips. Other, less-stringent residential land use policies can achieve smaller, but still significant, favorable changes in transit ridership. The paper concludes with a discussion of the problems associated with implementing corridor land use management policies.

Planners and urban policymakers have long recognized that a strong relation exists between urban development forms and the existence of rapid transit systems in cities. In recent years, new rail transit systems have not led to significant positive changes in urban development. It is believed that the existing high level of automobile accessibility tends to obscure the increases in mobility achieved by rail transit. Many planners and policymakers believe that rail transit systems can be more effective in meeting the travel needs of the public, can be more energy efficient, and can require less subsidy if land use planning in transit corridors can be coordinated with the planning of the rail system itself.

In this paper, a case study is reported that attempts to quantify the effects of implementing several alternative residential land use policies on transit patronage. There are major questions that need to be answered about the kinds of policies that should be implemented. Planners need to know, for example, what kinds of housing should be encouraged in transit corridors. Should land close to transit stations be reserved for high-density apartments or be kept open to provide large lots for park-and-ride patrons? Given that land use regulations are difficult to enact and enforce, how does noncompliance with the plan affect the desired results? Because of the many unanswered questions, this research was directed toward the development of a quantitative tool that would provide planners with the ability to determine the likely effects of alternative land use plans on transit ridership.

RESEARCH OBJECTIVE

The objective of the research was to develop a model that would take as input various housing policies and translate these results into transit ridership figures. The model was designed to estimate the proportion of commuters traveling by transit; the modal split, given that population could be clustered at various densities; and distances from the transit stops. By changing the location of population clusters, one alters the relative travel times and costs encountered in traveling to both transit stations and to the central business district (CBD).

In this analysis, only residential development was considered and, because of data limitations, only the journey from home to work was considered in modal-split modeling. These restrictions were imposed because it was desired to limit assumptions and variables as much as possible in order to achieve a controlled modeling environment, in which selected parameters could be varied while all others could be held constant. It was also desired to keep the analysis as simple as possible.

Mass transit ridership is known to depend strongly on residential density, and residential land comprises much of any transit corridor. Yet none of the previous work in joint development or transit corridor planning has examined the consequences of managing residential growth. Because most trips begin at home, changing residential location patterns will result in changes in trip-making patterns. It is thought that a plan that concentrates residential density in the vicinity of a transit line will produce more transit trips than one that allows for more dispersed growth. The model developed in this research seeks to test this theory and to indicate the sensitivity of transit ridership (for work trips) to residential location policies. Also of interest was the effect of housing policy on access modal choice (i.e., the means of travel to the transit station) and the effect on automobile vehicle miles of travel (VMT) for work trips.

CORRIDOR SKETCH-PLANNING MODEL

To proceed with the testing of this hypothesis, a corridor sketch-planning model was devised that incorporated a wedge-shaped corridor centered on a large CBD. A housing-allocation model was developed that permitted the quantification of several dimensions of likely residential development policies. Policy zones were created within the corridor based on distance to stations and distance to the CBD. The table belows gives the distances used in developing policy zones:

	Policy Zone Definition by Distance to CBD		
Distance to Station (miles)	0-7 Miles	6-11 Miles	>11 Miles
0	1	2	3
0-1	4	5	6
1-2	7	8	9
>2	10	11	12

Target residential densities could be specified for these zones, and a policy effectiveness level could be specified for the corridor, to determine the amount of land available for allocating new growth according to the target density. Special development districts were created at each proposed station to permit examination of the effects of highly concentrated growth strategies. Because few transit lines are likely to be built entirely in vacant corridors, an initial starting allocation of housing was used that was based on actual data from the case study area.

To test the model, a case study area was chosen in southern New Jersey. A proposed branch-line extension to the existing Port Authority Transit Corporation (PATCO) rail rapid transit system is currently under study, and the corridor it is projected to serve was chosen as a test area for the model. The triangular transit corridor, 30 miles long and 15 miles wide at the maximum, covers parts of Camden and Burlington Counties in New Jersey and includes a population of about 450 000. The initial data set used by the model comprises 60 variables recorded in the 1970 census, population projections for the year 2000, and developable land areas for each of the 116 census tracts that comprise the corridor. For the purposes of the research, some of these tracts were further subdivided into subzones, which increased the total to 212 subareas or zones for analysis.

INTERACTIVE MODEL STRUCTURE

The nature of the research suggested that a number of alternative policies would be tested. This, coupled with the magnitude of the data base, led to the use of an interactive computer approach that permitted quick evaluation of many policy scenarios in a short period of time with minimum data manipulation (1).

The program is comprised of a transit line routine, a housing-allocation model, a modal-split mode, and a routine to produce graphic output. These four routines are managed by a conversational program that controls the sequence of model execution and accesses the various routines and subroutines.

Transit Line Model

The transit line input routine allows the user to input a new transit line route, to reset the program to the planned version, and to add or modify the number and location of stations. The functions of this program are to (a) calculate the distance between each zone centroid and each station, (b) select the station nearest each zone based on the least weighted distance to all stations, (c) create around each station a new special development district zone (0.5 mile^2) to be superimposed on the original zones, and (d) assign to each zone a classification code based on the zone's location relative to both the destination--in this case the Philadelphia CBD--and the nearest station. The 0.5-mile^2 zone is created in order to enable the user to apply special housing-allocation policies to those areas within walking distance of the stations.

Housing Allocation

The housing-allocation model simulates a 1990 housing distribution by allocating specific increments of dwelling units to the 1970 base year. A distinction is made between unmanaged growth and policy-directed growth in new dwelling units. The policy-directed number of dwelling units is set by the user to simulate policies to increase development at locations within the corridor. The user specifies the number of new dwelling units to be added to the corridor and the target densities and distribution, which define the desired residential plan to be tested. The unmanaged dwelling units replicate population gains and losses projected by the Delaware Valley Regional Planning Commission (DVRPC) if no transit-related development were to be induced. Housing units are allocated to zones until target densities have been reached, and they are based either on existing density levels or on the basis of user-specified growth policies.

Specifying Development Policy Zones

Because there is so much vacant land in the corridor within each policy zone, to meet the higher target densities it was necessary to specify the order of allocating housing to the zones. The user assigns each policy zone a priority index from 1 to 12, with 1 representing the highest priority. The model takes the group of zones with the highest priority index and allocates to those zones a number of dwelling units to fill the vacant land at the specified target density, but not greater than the pool of dwelling units available for allocation. If the allocation of dwellings to this class of zones exhausts the vacant land, the program goes to the next priority class, and so forth, until the pool of dwelling units is allocated. If the pool to be allocated is greater than the capacity of the developable land (given the user-specified densities), the user is informed and allowed to adjust the input. Because of the large amount of vacant land in the corridor, it was necessary to adjust the input only when low densities or large increments of dwelling units were input.

The housing-allocation model first asks the user to input the total growth projected for the corridor, then the "percent effectiveness," which limits the policy-directed housing allocation. The percent effectiveness was used to examine the impact of backing-off or not enforcing the land use policies to be tested. It was, in effect, a sensitivity-testing mechanism. Because land use regulation is parochial in New Jersey, it was thought that only some communities would accept such land use controls. The percent effectiveness is the percentage of land to which the land use regulation would apply. Results of the runs in which percent effectiveness was less than 100 percent are not reported here. However, they were used as a guide in selecting policies to be tested.

Modal-Split Model

The modal-split model is an eight-mode, access mode stochastic choice model. The core of the program is a weighted logit function that calculates the probability of choosing a given mode. The modes are automobile, carpool, express bus, rapid rail via park-and-ride access, rapid rail with kiss-and-ride access, rapid rail with feeder bus access, rapid rail with walk access, and rapid rail with bicycle access.

The modal-split program calculates the impedance of each commuting trip to the CBD at the zone level, including (a) travel time spent in vehicle, (b) travel cost (cost in dollars later transformed to income-earning minutes), and (c) excess time, that is, time spent waiting for, transferring to, or accessing a mode. Travel time, cost, and excess time are multiplied by weighting coefficients and the terms summed. This exponential sum represents the total trip impedance, or disutility. The probability of choosing one mode is the ratio of its disutility to the sum of all modal disutilities. The zonal mode choice is expressed as the population of the zone, multiplied by the probability that an individual will commute to the CBD, multiplied by the probability of selecting each mode.

SPECIFYING HOUSING POLICIES

In most local land use, land, and zoning codes, residential land is zoned by lot size and dwelling type, e.g., town house, single-family detached, garden apartment, and high-rise apartment or condominium. Each type of housing can be accommodated by a variety of densities, depending on the amount of space allocated for dwelling units, open space, and parking. For this analysis, four basic types of housing are considered for policy allocation: high-rise apartments, midrise garden apartments, town houses or row houses, and single-family detached homes.

Each housing type is assigned a net density based on the appropriate number of stories usually observed, at-grade parking space for at least one car per dwelling unit, and a nominal amount of open space. In addition, it is assumed that residential development will require other development types in each zone as well. Thus, net density is translated into a gross density specification to take into account streets, schools, shopping centers, commercial development, and the like. It is assumed that gross residential density per zone is approximately equal to one-half the net density. The table below indicates the various density classes, both net and gross, for the four types of housing analyzed:

Housing Type	General Description	Target Densities (dwelling units/acre) Gross	Net
High-rise apartments or condominiums	10-story buildings with at-grade parking	45	90
Medium-rise housing	3- to 4-story garden apartments or town houses	15	30
Cluster housing	Single-family row houses or town houses	3-3.5	6-7
Low density	Single-family detached homes with 0.25-acre lots	2	4

To define a residential policy scenario, the desired housing types for each policy zone were indicated and translated into gross densities.

The gross densities were supplied to the model. The model was run and the results compared with a base case and with other policies. Except for gross residential density by policy zone, all other input variables and parameters were held constant for all model runs. Results were compared on the basis of modal split, access modal split, and automobile VMT. Table 1 summarizes the relevant statistics for each housing policy. Figure 1 shows schematic diagrams for each housing policy.

Base Case: No Transit-Related Development Policy

For the base case, it was decided to use year 1990 population projections for the corridor. The base case would serve as a reference for comparing the effects of policies after a 20-year growth period, assuming that land development policies were implemented in 1970, the year in which the initial data base was collected. Year 2000 population projections were obtained by minor civil division from DVRPC. Year 1990 population was obtained through linear interpolation of year 2000 projections. It was assumed that gross residential densities would remain close to those that existed in 1970. According to DVRPC projections, most growth will occur in the outermost portions of the corridor. Some areas closer in to Camden are projected to lose population.

Total growth is set at 29 675 dwelling units, or 100 272 individuals, over the 20-year period. Some 4555 dwelling units will be lost, for a net growth of 25 120 dwelling units. Approximately 10 percent of the vacant land (204 927 acres in 1970) will be required to accommodate the new growth composed mainly of single-family dwellings. The gross residential density would decrease from 2.21 to 1.95 dwelling units/acre.

The 1970 base case was used to calibrate the modal-split model. The 1970 transit ridership was set at 13 116 for comparison with existing Lindenwold Line ridership and with independent estimates developed by consultants for the projected Mt. Laurel extension (2). For 1990, this produced a transit modal split of 29.5 percent, or 18 572 daily riders. It should be noted that modal split was performed only for individuals with work trip destinations accessible by transit, primarily in the Philadelphia CBD. Access modal split was calculated to compare it with current Lindenwold Line figures, with the exception that more feeder bus service would be provided to the Mt. Laurel extension. Thus, park-and-ride is used by 60 percent of the transit users, with 10 percent walking and 10 percent using the feeder bus service. Tables 2-5 indicate the relevant model results for the various policies and the base case.

Policy 1: High-Rise Development in Special Districts

The first policy tested examined the effect of confining all new growth to 0.25-mile^2 special development districts centered on each transit station. It was assumed that all new construction would occur in the form of 10-story buildings that contain apartments or condominiums at a target net density of 90 dwelling units/acre. Sufficient vacant land was available in the 12 special development districts to achieve a net density of 65 dwelling units/acre, which corresponds to a gross residential density of 32.5 dwelling units/acre.

Two further variations of this policy were tested in order to examine the relative changes in ridership when development was stressed at the outermost or innermost stations. The high-rise, outer-station policy groups most of the projected development at the four outer stations and the remainder at the four intermediate stations with a net target density of 90 dwelling units/acre. The high-rise, inner-station policy concentrates growth at the inner station (downtown Camden) and the four intermediate stations.

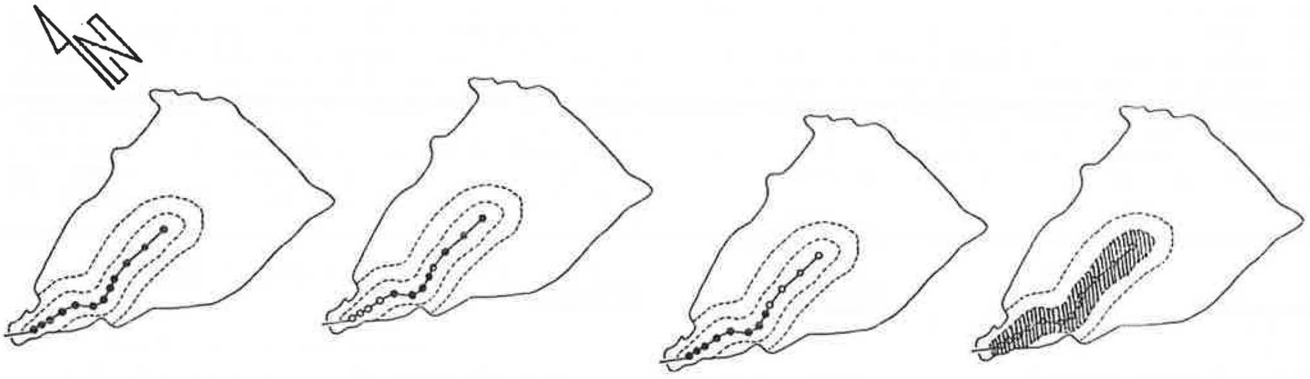
Concentration of all growth in the 12 station zones increases transit ridership by 2089 riders/day, or 11.2 percent over the base case. Significant changes in access mode distributions are seen as well. Most notably, park-and-ride users are down by 27.5 percent--a decrease of 3220 patrons. At an assumed averge automobile occupancy of 1.5, the model indicates that more than 2000 parking spaces could be eliminated. Walk-and-ride patronage more than doubles, and the numbers of feeder bus and kiss-and-ride patrons show significant increases as well. A sharp drop of 19.4 percent in total automobile VMT for work trips is seen. Automobile average trip length declines as well, which reflects decreased time spent in commuting to work, whereas transit passenger miles of travel (PMT) increase slightly.

Variations on the high-rise policy were tested because the target density is sufficiently high (net, 90 dwelling units/acre; gross, 45 dwelling units/acre) to permit housing to be concentrated in only 8 of the 12 station sites. To fill all 12 special districts, net and gross densities need only be 65 and 32.5 dwelling units/acre, respectively. The first variation examined the effect of developing

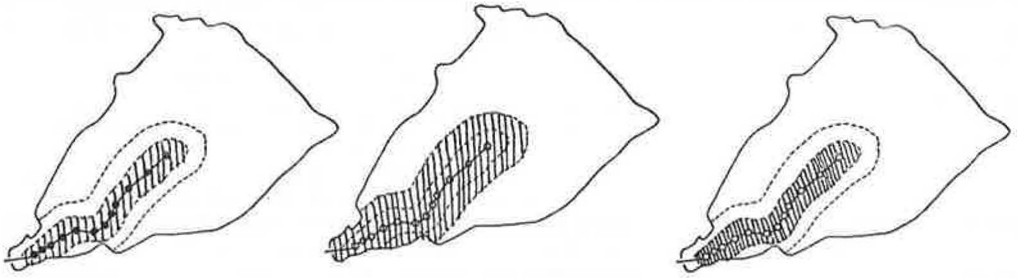
Table 1. Land use summary.

Policy	Land Consumed (acres)	Vacant Land Remaining (acres)	Avg Density in Growth Zones (dwelling units/acre)	
			Before	After
Base case	22 839	184 179	0.47	0.57
High-rise, all stations	913	206 104	3.25	15.61
High-rise, outer stations	659	206 358	1.71	25.74
High-rise, inner stations	659	206 358	4.39	19.60
Clustered, expanded density	8 768	198 249	1.65	3.01
Midrise and low density	8 709	198 308	3.25/1.49	9.2/2.41
Low density, 2-mile radius band	14 839	192 178	0.77	1.88
Clustered, 1 mile	7 927	199 091	1.67	3.10

Figure 1. Housing policies—schematic diagrams.



A : High Rise/Special Districts B : High Rise/Outer Stations C. High Rise/Inner Station D : Clustered/1 Mile Band



E : Mid-Rise and Low Density F : Low Density 2 Mile Band G : Clustered 1 mile "Ring"

the outermost four stations at the target density and the middle four stations at a net density of 66 dwelling units/acre. Because the comparative advantage of transit versus automobile increases with trip length, the model produces even higher transit ridership, up 2918 over the base case for an increase of 15.7 percent. Park-and-ride space requirements decrease by 25.1 percent, and automobile VMT is down by 19.6 percent. Because of the increased concentration of riders at the outer stations, the total transit PMT increases by 9.8 percent, which reflects longer average transit trip lengths.

Concentrating housing at the stations closest to the CBD produces a less-dramatic increase in modal split of 8.2 percent, or 1530 patrons. Park-and-ride patronage drops by 28.5 percent, total automobile VMT decreases by 19.4 percent, and transit PMT decreases by 6.9 percent, which reflects a shorter average transit trip length.

Policy 2: Cluster Development

In defining the policy of cluster development, it was desired to examine the impact of clustered housing similar to that commonly associated with planned unit developments or urban row housing. The policy specified that new residential development could only take place within approximately one mile of the stations. An overall net residential density of 6.4 dwelling units/acre was achieved over 9273 acres of land. Within the special development districts, 2931 dwellings are accommodated.

Clustering housing within one mile of the transit stations increases transit patronage by 4.8 percent, or 8952 daily riders. Although the increase in transit ridership is not great, the policy still results in major reductions in park-and-ride patronage

Table 2. Model output for base case and alternative policies—base statistics.

Category	Transit (%)	Transit Ridership	Change Over Base (%)
Base case	29.5	18 572	0.0
High-rise in special districts			
All stations	32.8	20 661	11.2
Outer stations	34.2	21 490	15.7
Inner stations	32.0	20 102	8.2
Clustered expanded districts	31.0	19 469	4.8
Midrise and low density	31.7	19 930	7.3
Low-density, 2-mile radius band	29.8	18 772	1.1
Clustered, 1-mile radius ring	30.8	19 361	4.2

(23.4 percent) and automobile VMT (16.4 percent) for CBD-bound commuters.

Policy 3: Midrise Development

The policy of midrise development is an attempt to create gradations of density around the transit stations. Within the special station development districts, only midrise housing (3-4 stories) at a net density of 30 dwelling units/acre would be permitted to accommodate new growth. Within the one-mile rings, development at 4 dwelling units/acre would be permitted. Other portions of the corridor would be restrained from further growth. With this distribution of densities, 10 742 dwelling units are accommodated within the special development districts. The remaining net growth of 14 378 units can be accommodated within the one-mile rings around the station.

Developing the station development districts with midrise housing and concentrating low-density development around them provides more support for the transit line than the base case. A ridership increase of 7.3 percent (1358 daily riders) is projected. Park-and-ride patrons decrease by 25.1 percent, and total automobile VMT is down 17.6 percent.

Table 3. Model output for base case and alternative policies—access modal split.

	Park-and-Ride		Kiss-and-Ride		Feeder Bus		Walk-and-Ride	
Category	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)
Base case	11 689	0.0	2804	0.0	1874	0.0	1852	0.0
High-rise in special districts								
All stations	8 469	-27.5	3648	30.1	2185	16.6	5611	202.9
Outer stations	8 638	-25.1	3785	35.1	2257	20.4	6017	224.9
Inner stations	8 353	-28.5	3556	26.8	2135	13.9	5341	188.4
Clustered expanded districts	8 952	-23.4	3764	34.2	2291	22.2	3815	106.0
Midrise and low density	8 752	-25.1	3711	32.3	2246	19.8	4533	144.7
Low density, 2-mile radius band	9 273	-20.7	3662	30.6	2281	21.7	3011	62.6
Clustered, 1-mile radius ring	9 009	-22.9	3782	34.9	2305	23.0	3627	95.8

Table 4. Model output for base case and alternative policies—automobile VMT.

	Automobile VMT										On-Line Transit (PMT)	
	Drive Alone		Carpool		Park-and-Ride		Kiss-and-Ride		Total			
Category	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)
Base case	318 745	0.0	96 100	0.0	64 923	0.0	9052	0.0	488 821	0.0	213 914	0.0
High-rise in special districts												
All stations	285 627	-10.4	73 961	-23.1	27 257	-58.0	6886	-23.9	393 732	-19.4	215 539	0.7
Outer stations	284 186	-10.8	74 244	-22.7	27 298	-58.0	6954	-21.1	392 682	-19.6	234 877	9.8
Inner stations	287 360	-9.8	73 925	-23.1	27 228	-57.9	6841	-24.4	395 345	-19.1	199 154	-6.9
Clustered expanded districts	295 576	-7.3	76 879	-20.0	28 211	-43.4	7913	-12.6	408 577	-16.4	204 288	-4.5
Midrise and low density	291 652	-8.5	75 711	-21.2	27 822	-57.1	7490	-17.2	402 675	-17.6	208 780	-2.4
Low density, 2-mile radius band	301 160	-5.5	78 676	-18.1	29 742	-54.2	8862	-2.1	418 441	-14.4	199 154	-6.9
Clustered, 1-mile radius ring	296 625	-6.9	77 192	-19.6	28 311	-56.4	8032	-11.3	410 168	-16.1	203 218	-5.0

Table 5. Model output for base case and alternative policies—automobile average trip length.

	Automobile Avg Trip Length (miles)										On-Line Transit Avg Trip Length (miles)	
	Drive Alone		Carpool		Park-and-Ride		Kiss-and-Ride		Total			
Catogory	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)	No.	Change Over Base (%)
Base case	11.00	0.0	12.50	0.0	5.55	0.0	3.23	0.0	9.6	0.0	11.50	0.0
High-rise in special districts												
All stations	10.11	-8.1	10.57	-15.4	3.22	-42.0	1.89	-41.5	8.32	-9.0	10.47	-9.0
Outer stations	10.31	-6.3	10.75	-14.0	3.16	-43.0	1.79	-43.0	8.73	-5.1	12.08	5.1
Inner stations	10.03	-8.8	10.46	-16.3	3.26	-41.3	1.93	-41.3	8.30	-9.0	10.47	-9.0
Clustered expanded districts	10.19	-7.4	10.69	-14.5	3.15	-43.2	2.10	-34.9	8.35	-5.8	10.83	-5.8
Midrise and low density	10.15	-7.7	10.64	-14.9	3.18	-42.7	3.33	3.2	8.34	-4.4	10.99	-4.4
Low density, 2-mile radius band	10.21	-7.2	10.76	-13.9	3.21	-42.2	2.42	-25.1	8.41	-7.1	10.69	-7.1
Clustered, 1-mile radius ring	10.20	-7.3	10.69	-14.5	3.14	-43.4	2.13	-34.2	8.35	-6.0	10.81	-6.0

Policy 4: Restraints on Outer Corridor

The objective of the policy of restraints on the outer corridor is to prevent new growth from spreading to the outermost areas of the corridor by directing growth into areas within two miles of transit stations. Some 14 838 acres of land are required to accommodate the expected population increase at an average net density of 4 dwelling units/acre.

For each of the preceding policies, the model produced similar levels of reduction in park-and-ride patronage and automobile VMT reductions. This is largely due to the fact that all policies tested prevent growth in the outer exurban portions of the corridor and shift dwellings closer to the CBD. Policy 4 examines only the issue of restraining outward growth and provides a useful reference. The increase in transit ridership is only 1.1 percent, or 200 commuters. Thus, it is clear that outer-corridor development restraints alone will not significantly affect modal choice, although the access modal choice and automobile VMT figures have been affected significantly by the policy. Automobile VMT reduction (14.4 percent) due to this policy accounts for at least three-quarters of the VMT savings exhibited by the model for the other policies examined.

Policy 5: Residential Rings

The policy of residential rings examines the effect of preventing residential development in the station special development districts proper and creates medium-density rings within one mile of each station. Residential development would be prohibited in other locations. It is assumed under this policy scenario that the station special development districts would be devoted exclusively to nonresidential development. The rings are developed at a net density of 3.55 dwelling units/acre, which uses 8359 acres of vacant land.

By clustering new housing closely along the line, but outside the station districts, a 4.2 percent ridership increase is forecast. This policy is used as a further reference case for comparison with policy 3 (midrise development). The effect of controlling growth in the outer corridor and creating a band of housing, even at fairly low density, has a considerable effect on transit ridership. By comparing the access mode distributions, it can be seen that this policy favors the use of feeder bus and kiss-and-ride more than any of the other policies tested.

CONCLUSIONS

The model results show that residential land use policies have a significant impact on both transit ridership and access mode patronage. By necessity, the policies tested here embodied growth constraints on exurban land. The restraint policies are equally as important as the policies that increase densities in the areas near transit itself. Even without transit service, it is likely that the concentration of growth will have beneficial effects on CBD-bound VMT by reducing the average trip length. It should be noted, however, that the model does not consider trips to other destinations not served by transit. If large numbers of work trips are made to these other locations, it would be inappropriate to use the results of this model to infer a growth policy for the corridor.

Within the land envelope that surrounds the transit line there is a sharp increase in transit ridership as density increases in the immediate vicinity of the stations. Results produced by the model indicate that a maximum ridership increase of 15.7 percent can be attributed to growth concentration; lower densities produce smaller, but still significant, increases. Ridership is increased most when residential development is concentrated at the outermost stations because the comparative advantage of transit increases with distance. The target density of the first policy is clearly too high according to current norms for suburban development. Some, but surely not all, development could take place in high-rise buildings.

Implementation of a growth management policy similar to those tested here would inevitably present great problems. In the New Jersey study corridor, for example, strong home rule exists, and zoning and land use decisions are made largely by the municipalities with little interference from county, state, and regional planners. The decision to restrict or encourage growth in a community, although legally feasible, will be controversial and hotly opposed. When similar decisions must be made for a number of communities, the likelihood that a consensus could be achieved on an appropriate growth management policy becomes slim indeed.

However, in areas where political jurisdictions are more homogeneous and enlightened public officials are concerned about efficient patterns of urban form, it may be possible to link a strong land use management policy to transit development. In many of the urban areas where transit systems are under construction today, such political conditions do exist, because they are the same conditions needed to promote the construction of a transit line.

Although the results of this analysis are far from definitive, they provide a direction for further research. The eventual goal should be a method for quantifying and evaluating the effects of joint development on a community. In the model developed in this research, only a limited number of factors were examined: modal split, access mode split, VMT, and transit PMT. Many other factors should be included as well, and the analysis extended to the entire trip-making pattern of an area. Also, capacity constraints were not included, nor were effects of congestion. The simplified model presented here allows the examination, in isolation, of the effect of density on modal split. As more information is accumulated, UMTA may well find evidence that would justify the requirement for a transit corridor land use management program that involves joint development as a prerequisite for transit construction funding.

ACKNOWLEDGMENT

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Abridgment

Analysis of Fare-Collection-System Dependability

DAVID I. HEIMANN

The collection of transit system fares has become more sophisticated in recent years with more flexible fare structures. However, the more complex equipment such fare structures require has often been plagued by reliability problems, which results in significant passenger congestion and delay. Although development efforts are under way to improve reliability, one needs to know by how much the reliability needs to be improved. Attempting either too small or too large an improvement may result in a waste of transit funds and/or no relief from the congestion and delay problems. In order to determine the amount of improvement necessary, a method is needed to determine the dependability of a fare-collection system, i.e., the passenger congestion and delay in the system, given its demand, capacity, reliability, maintainability, etc. This paper discusses how a dependability analysis can be used to obtain reliability and other specifications and presents models to carry out such an analysis. Various types of dependability analyses are described (evaluation, sensitivity analysis, specification determination, and trade-off analysis), and purposes for which transit systems can use such analyses are discussed. Simulation and analytical models to evaluate fare-collection-system dependability are presented, as well as the data requirements for the models. A sample fare-collection dependability analysis that uses data based on an actual transit system is described, and the results and conclusions are discussed.

The collection of transit system fares has become more sophisticated in recent years as transit authorities turn to more flexible fare structures. As the use of extra personnel is often too costly, transit systems have turned to more sophisticated fare-collection machinery, which uses data processing and electronics in order to carry out the more involved fare-collection procedures that arise from such structures (1-4).

However, the newer and more complex a piece of equipment, the more likely it is to have frequent failures. High failure rates have indeed occurred, which leads to significant passenger delay, lower throughput capacity, and general frustration (5,6). Efforts are under way to increase the reliability of fare-collection equipment (5-8). The question that arises, however, is by just how much should the reliability be improved. Under some circumstances, the reliability improvement and its related monetary expenses may be ineffective.

For example, the improvement may be in the wrong service area. Either the main delay does not occur in the service area being improved or the improvement merely causes the delay to shift to a service area further downstream, with no decrease in overall delay.

Another possibility is that the reliability may be improved too much. When the reliability improvement is large enough, failures no longer happen often enough for further improvement to significantly affect system operation.

Measures other than reliability improvement may be more effective. Faster recovery times (i.e., maintainability) or having more units available for service (i.e., redundancy) may improve system performance as well as or better than reliability improvements and may be less expensive.

Finally, system failure may not be the main problem. Large surges of simultaneously arriving passengers, such as those coming from a major feeder bus line, may cause large delays.

In order to properly answer the question, By how much should reliability be improved?, one needs some way to find out the passenger delay in a fare-collection system, given information on its reliability, maintainability, number of machine units (redundancy), nominal processing rate, and passenger demand. In this manner, one can derive the proper mix and extent of improvements necessary.

Described in this paper are models that have been developed to examine the interrelation among reliability, maintainability, number of machine units, and passenger delay by analyzing the flow of passengers through the fare-collection system. These models treat the system as a network of queues, with the passengers moving from one service area to the next (a service area is a specific set of machine units, such as coin and bill changers, ticket vendors, gates, etc.). Superimposed on this network is the failure-recovery process by which units fail at a rate according to their reliability and are repaired according to their maintainability.

ANALYSIS PROCESS

The models calculate the congestion (queue length) and passenger delay in the fare-collection system, given the system configuration and passenger demand, for each of the service areas (i.e., ticket vendors, gates, etc.) in the system, as well as the delay for the overall system.

The models make possible at least four kinds of analyses: evaluation, sensitivity analysis, specification determination, and trade-off analysis. In evaluation, a given fare-collection system is examined, with the required information about the system collected and entered into the model as input data. Sensitivity analysis measures the sensitivity of congestion and delay to changes in input parameters (especially useful if one wishes to make changes or if some of the input parameters are questionable). Specification determination assesses the values of selected input parameters necessary to achieve a desired goal for congestion and delay (this is the reverse of sensitivity analysis, in that it measures the sensitivity of the selected input parameters to the congestion and delay goals). Trade-off analysis examines how two input parameters can be changed, with one being raised in quality while the other is lowered in quality, while keeping the overall performance constant (as compared with sensitivity analysis, which examines the interaction between an input and an output parameter).

The results produced by the fare-collection model are useful to transit properties for a number of different purposes, such as

1. Determination of required number of machine units,
2. Reliability and maintainability specifications,
3. Impact of changes in passenger demand,
4. Effect of maintenance policy changes, and
5. Effect of changes in fare-collection method.

TECHNICAL APPROACH

The basic approach to the model is to investigate the operation of the fare-collection system as a multiple-server queue, with passengers as customers, machine units as servers, and a first-come, first-served service discipline. In addition to the normal queue features, the number of servers (machine units) changes as the machine units fail and are repaired.

Simulation Model

Several machine units, each of which can serve one passenger (provided they are not otherwise busy or out of service because of failure), make up a service area. The simulation model has up to three service areas in sequence. Arriving passengers are assigned to initial service areas according to a given passenger-flow division. After completing service at a service area, a passenger continues to the next area until the service is completed at the final area (usually the gates), at which point the passenger departs the system. The model is an event-oriented simulation in which the next event to be processed is the earliest-occurring of the five basic events: passenger arrivals, passenger departures, equipment breakdown, equipment repair, and passenger continuation to the next service area. Events are processed until the time of the prospective next event is no longer within the time period being simulated.

On arrival, a passenger immediately begins service if a machine unit is available, in which case a departure time is calculated and put into the departure stack (which is an array of departure times of passengers in service, sorted in chronological order, used to determine the time of the next departure). If no machine is available, however, the passenger enters a first-in, first-out queue.

Passengers who find an available unit on arrival and thus immediately enter service have delay times of zero. Passengers who enter service from the queue have their (nonzero) delay times calculated at the time they enter service. The delay time is the interval between the arrival time and the time of entry into service. On departure, the passenger record is removed from the departure stack.

The reliability of the equipment being modeled is given in terms of the mean cycles between failures (MCBF). On the departure of a passenger from service, a random draw is made with probability 1/MCBF that the machine unit just used breaks down. If it does break down, its repair time is calculated and the unit is placed in the repair stack (which is an array of return-to-service times of failed units arranged in chronological order). In addition, if a breakdown occurs, the number of machine units available is decreased by 1.

The time necessary to repair a failed unit is assumed to be an independent random variable with an exponential distribution. (Note, the interarrival times between successive passengers and the passenger processing times are also assumed to be independent and exponentially distributed.) Repair time (maintainability) includes the time to report the failure and dispatch repair personnel as well as the time to actually do the repair. On repair, the unit is removed from the repair stack and the number of units available is increased by 1. If a queue exists when a unit returns to service, the first passenger in the queue enters service.

A passenger continuation is a departure by a passenger from an upstream service area to the next one in sequence. A continuation is treated as a simultaneous departure at one area and arrival at the next one in sequence.

Analytical Model

A simulation model does have some drawbacks. The randomly obtained congestion and delay probability distributions are subject to a number of statistical sensitivities; therefore, the simulation must be run several times for each situation. Furthermore, a simulation will require a large amount of computer time if many passengers must be processed, as would be the case at an important station during the peak period, which is the type of station one would most likely wish to investigate. Therefore, the simulation will require a large amount of computer time to carry out its analysis.

Therefore, in addition to the simulation model, an analytical model was developed to examine a fare-collection system. The analytical model directly solves the equations for the queue length probabilities from which the mean (and variance of) congestion and delay are obtained by using a modification of the Neuts and Lucantoni model (9) for the multiple-server exponential queue with a randomly varying number of servers. The analytical model needs to be run only once, as it avoids the statistical sensitivities that affect the simulation model, thereby reducing the amount of computer time required for the analysis.

DATA REQUIREMENTS

Two kinds of data are required for the model: hardware and passenger flow. The hardware data include reliability and maintainability data as well as the passenger processing rate per machine unit and the number of units provided for each of the service areas in the station. The passenger-flow data include the passenger arrival rate, group size, and division of passenger flow to the various service areas. Specifically, the data requirements are as follows:

1. Passenger arrival rate (one parameter for the entire system): The hourly rate at which passengers arrive at the fare-collection system during the peak period.
2. Group size (one parameter for the entire system): The size of a group of arriving passengers.
3. Passenger processing rate (one parameter for each service area): The hourly rate at which a machine unit in the service area can process passengers, and hence the unit's capacity to handle passenger flow. (Note, the actual rate in the field will be significantly less than the machine design capacity because of various types of passenger-induced delays. A special collection effort may need to be made to obtain this rate.)
4. Failure rates or reliability (one parameter for each service area): The rate at which failures occur to a machine unit, which makes it unable to process passengers. Because the basic measure of exposure to failure is the use of the unit by an individual passenger, the measure of failure rate is given as MCBF.
5. Repair times or maintainability (one parameter for each service area): The elapsed time (in hours) between the failure of a machine unit and its return to service. This is the sum of the times necessary to detect the failure, dispatch repair personnel, and perform the actual repair.
6. Number of machine units (one parameter for each service area): The number of machine units nominally available for passenger use in the absence of failures.
7. Division of passenger flow to service areas (one parameter for each service area): The proportion of arriving passengers who begin their use of the fare-collection system in that particular service area.

SAMPLE ANALYSIS

In order to demonstrate the use of the model for fare-collection-system analysis, a sample run was made based on preliminary data obtained from the Miami Dade County Transit Authority (the analysis is

Table 1. Effects of changes in number of gates and their reliability and maintainability.

Case	Gate Arrival Rate (per hour)	No. of Gate Units	Reliability (MCBF)	Maintainability[a] (h)	Gate Processing Rate (per hour)
1	5400	5	60 000	0.8	1350
2	5400	5	10 000[b]	0.8	1350
3	5400	5	3 000[b]	0.8	1350
4	5400	5	1 000[b]	0.8	1350
5	5400	6[b]	1 000[b]	0.8	1350
6	5400	5	1 000[b]	0.6[b]	1350
7	5400	5	1 000[b]	0.3[b]	1350
8	5400	5	1 000[b]	0.2[b]	1350
9	5400	5	1 000[b]	0.1[b]	1350
10	5400	4[b]	3 000[b]	0.8	1350

[a] Mean total downtime.
[b] Changes from base case (case 1).

of course based on preliminary configurations and does not necessarily reflect the final configuration of the actual Miami system).

The station analyzed in the model run is derived from the Dadeland North station during peak-hour operation. This station was selected because it is a relatively important station that has enough passenger demand to result in significant congestion and delay if enough machine units fail. The estimated peak-hour passenger flow at the sample station is 5400 passengers/h. Passengers are assumed to arrive singly, not in groups.

There are five gates at the station. Each gate has a physical capacity to process 1800 passengers/h. A rough rule-of-thumb for field processing capacity of 75 percent of the physical processing capacity is assumed for this analysis. Therefore, the gate processing rate used in the model runs is 0.75 x 1800, or 1350 passengers/h.

The reliability is 60 000 MCBF. The mean total downtime due to a failure (MTTR) is 0.8 h (48 min).

The analysis investigates the effects of changes in the number of gates and their reliability and maintainability. Ten cases are examined, as given in Table 1. The results for the gates are as follows [note, * = infinity (queue length exceeds 500)]:

Case	Mean Queue Length (congestion)	Mean Passenger Delays Excluding Processing Time (s)
1	3.2	0.5
2	3.2	0.5
3	9.2	6.6
4	40.2	34.1
5	3.3	2.6
6	28.0	24.2
7	20.4	16.7
8	7.3	4.6
9	5.3	2.6
10	*	*

A number of conclusions can be drawn from these results:

1. Evaluation of the given situation (case 1): no serious delay problems are expected from the fare-collection system as specified.
2. Sensitivity analysis of gate reliability (cases 1-4): The specification for gate reliability can be significantly reduced from its original level of 60 000 MCBF without seriously affecting delay. In fact, the reliability can decrease by almost an order of magnitude without serious impact. Delays start becoming significant when the MCBF reaches 3000 and become a problem when the MCBF reaches 1000.
3. Sensitivity analysis of increased number of gates under conditions of low reliability (cases 4 and 5): Adding one additional gate, which makes six units in all, when the gate reliability is low (1000 MCBF) is equivalent to improving the reliability to 10 000 MCBF.
4. Sensitivity analysis of maintainability under conditions of low reliability (cases 4 and 6-9): A delay problem due to low reliability can be solved for this system by improving maintenance response, but the improvement must be considerable (even an improvement from 0.8 to 0.1 h does not completely restore the performance of the base case).
5. Sensitivity analysis of decreased number of gates under conditions of marginal reliability (cases 3 and 10): The system cannot operate with fewer than five gates. If failures occur under a four-gate operation, the system will sustain catastrophic congestion and delay.
6. Trade-off analysis of reliability versus maintainability under conditions of low reliability (cases 3, 4, and 8): An increase in the reliability (of case 4) from 1000 to 3000 is approximately equivalent in delay impact to an improvement in the maintainability from 0.8 to 0.2 h.

SPECIAL NOTE

To supplement the above models, a cost module has been developed that computes the annual costs relevant to fare-collection dependability (i.e., equipment acquisition costs, spares costs, equipment operating costs, and scheduled and corrective maintenance costs). The module makes possible such analyses as cost/performance evaluations, sensitivity analyses of costs to changes in specifications, trade-offs between costs and performance, and trade-offs between different types of costs. A full-length report that describes in detail the models discussed in this paper, as well as the cost module, is available on request from the author.

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Bus Terminal Planning and Operation at the 1982 World's Fair

DAVID R. MILLER AND M. JANET REID

The design and operation of charter and tour bus and shuttle bus terminals at the 1982 World's Fair in Knoxville, Tennessee, are described. Constraints governing the design principles are discussed and operation policies are defined. Each terminal required a different type of layout and operating concept because of land availability and differences in the loading and unloading requirements of users of the types of services offered. Operating labor requirements, other factors influencing cost, and flow rates actually achieved at each terminal are discussed.

The 1982 World's Fair in Knoxville, Tennessee, was planned to attract 11 million visitors during its six-month duration. A modal split of 30 percent by public transit was predicted for the designed day volume of 80 000 persons. The public transit component of the Fair's planned transportation system included provisions for charter and tour buses; shuttle buses from local hotels, motels, and nearby communities; shuttle buses from parking lots included in the official World's Fair parking system; and the local bus service provided by the Knoxville Transit Authority through its operating arm, K-TRANS. Early estimates were that, on peak days, 700-800 charter buses might arrive, carrying some 30 000 Fair visitors. The local hotel and motel shuttles were predicted to carry a maximum of 5000 visitors/day, and the official parking lot shuttles an additional 10 000 visitors on peak days. (The parking lot shuttles, both official and unofficial, were counted as part of the automobile modal split and thus were not included in the 30 percent forecast.)

The World's Fair site (see Figure 1), which is bounded by the Knoxville central business district (CBD) to the east, the Tennessee River to the south, the University of Tennessee campus to the west, and an Interstate highway and local arterial streets on the north, posed many challenges to the transportation planners. The overall goal was to get visitors to and from the Fair as efficiently as possible while imposing a minimum of added congestion on the Knoxville street and highway system. Planners for the Fair's transportation system had to work within the following constraints:

1. Land adjacent to the Fair was scarce and costly,
2. The Fair management wished to invest the minimum amount possible in transportation facilities consistent with the goals stated above,
3. Charter and tour buses required parking for the day as well as terminal facilities for loading and unloading,
4. Terminal plans had to be compatible with existing or achievable highway capacity on the adjacent streets, and
5. The terminal system and traffic-flow rates had to mesh with the Fair's entrance gate designs and capacities.

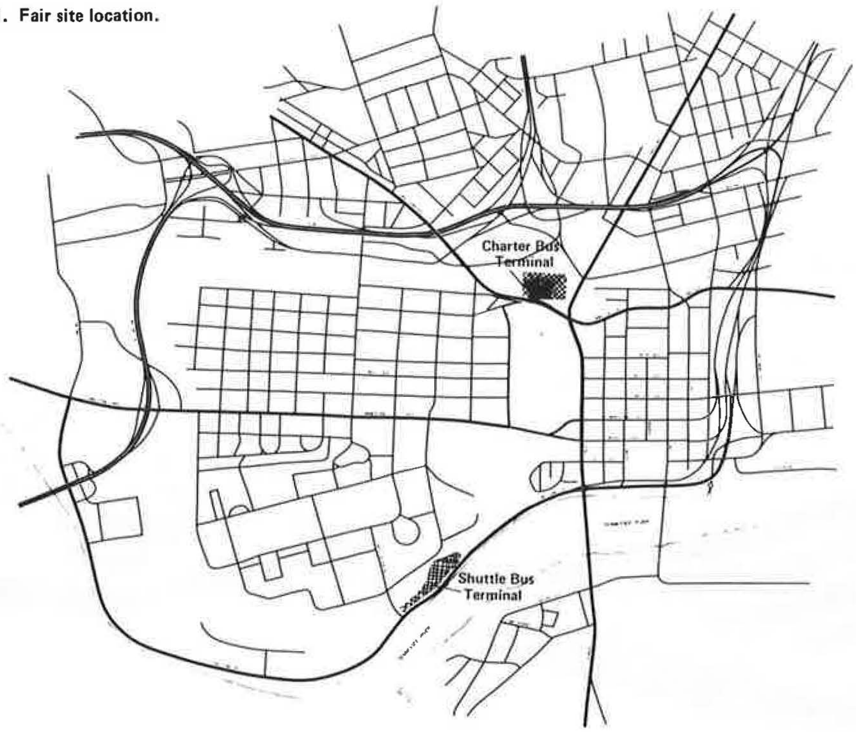
The solution adopted was to assign the different types of bus traffic to terminals at the various Fair gates, thereby distributing the volumes and enabling the most appropriate type of facility to be designed for each kind of service. The design and operation of each of the three bus terminals are described in the remaining sections of this paper. Information on operating labor requirements and flow rates achieved is included for each type of terminal.

CHARTER AND TOUR BUS TERMINAL

A charter or tour bus was defined as a bus that transported a group to the Fair, dropped off the passengers, and then picked them up at a designated time. The buses used were typically standard intercity coaches or school buses with one front door for loading and unloading.

The area designated for the charter terminal was a triangular piece of land immediately adjacent to the Fair's north gate. It was selected because of its proximity and ease of access to the Interstate highway system that serves Knoxville, which made it possible to keep most of the long-haul bus traffic off the downtown Knoxville streets en route to and from the Fair. A policy decision was made that charter and tour buses would unload at a Fair gate, but that no attempt would be made to provide all-day parking for the buses in the immediate vicinity of the Fair due to lack of land. Hence, buses would have to deadhead to a parking area immediately on unloading and return to the bus terminal only to pick up their passengers and depart for the next destination. Anticipating the need for fueling, dumping station, and cleaning services, as well as minor maintenance, Fair management entered into an agreement with a local entrepreneur to provide parking for a minimum of 175 buses, with room for an additional 250 to be provided if demand warranted. Servicing and minor maintenance were to be available at the same location, which was approximately 4.5 miles from the north gate. Proposals were solicited from existing bus facilities to provide the layover area based on services available and acreage.

Figure 1. Fair site location.



Terminal Layout

With the terminal being used solely for loading and unloading, maximizing the capacity of the facility to handle the movement of people and buses to and from the Fair was the primary design criterion. Several alternative configurations for the terminal were drawn up and analyzed, and the one selected is shown in Figure 2 (note that dark areas are pedestrian islands). The capacity of the terminal was maximized by using a layout that would allow the greatest number of buses to unload or load at a given time. This meant locating the loading berths in long rows and operating the terminal in a manner that would prevent bottlenecks from occurring on the platforms. Passing along the loading berths was not permitted due to space constraints. Arrivals at the Fair were handled on a first-come, first-serve basis, and a reservation system for departures from the Fair was established. The reservation system was widely publicized through the American Bus Association, the National Tour Brokers Association, and the Fair's group sales office. Brochures were distributed that outlined the terminal operating procedures, and site tours were conducted in March to familiarize tour operators with the terminal facility.

Two loading berths were provided for buses carrying handicapped persons along the west pedestrian walkway. These buses were permitted to park in the terminal; however, only one bus operator used the facilities throughout the course of the Fair.

Operating Plan

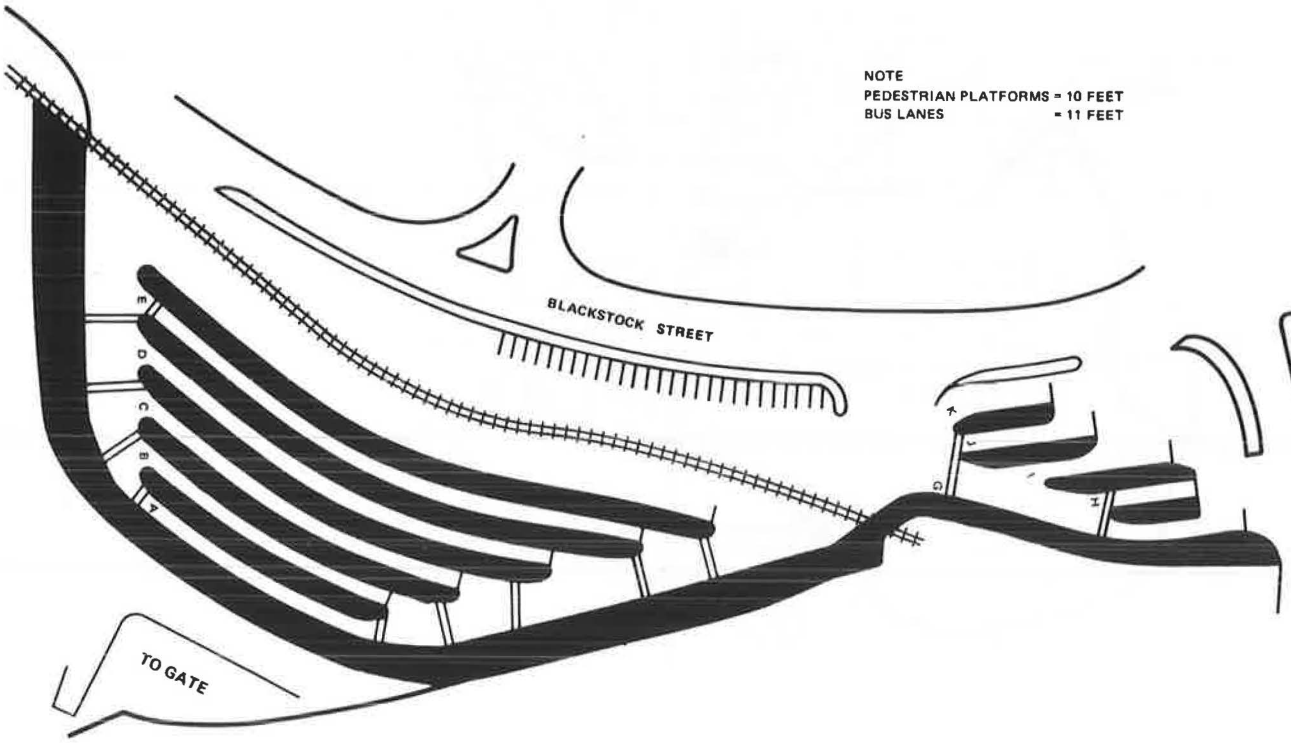
Greyhound, as official motor coach carrier of the World's Fair, was permanently assigned platforms A and B, with a total of 15 loading berths. The Trailways organization was assigned platform E, with eight berths. These platforms were operated by dispatchers from the respective carriers who were responsible for managing their traffic so as to avoid delays and to accommodate their scheduled departures. Greyhound chose to marshal their departures at their parking and layover area several miles from the Fair and to convoy the buses from there to the Fair in departure sequence. They were able to assign each bus a specific loading berth in this way and to tell the passengers where the bus would be along the platform. Trailways, which is an association of carriers rather than a wholly-owned operation, assigned their departures to the requested hour and used two-way radios between the terminal and their Knoxville garage to regulate flow during busy hours.

The remaining 31 berths in the terminal were operated by Fair staff. Fair dispatchers were stationed on platforms C, D, and F through J to greet incoming buses and assign or verify the departure time. Buses were assigned a sequence number for the day, which matched the number of the reboarding checks given the driver or tour escort to hand to the passengers. Passengers were told at which platform the bus would load and the departure time. The bus also was issued a windshield card that served as the pass to allow the bus to reenter the lot for loading. This card indicated the sequence number, the departure hour, and the platform assigned for loading. By recording the sequence number in the day's log, the dispatcher also could assist passengers in locating their bus; the log indicated which sequence numbers would be loading at each platform by time of day. Charter operators originally estimated boarding and alighting times of 10-12 min. Actual boarding and alighting times were 4-8 min. This was partly due to limited use of under-the-floor luggage compartments. Wheelchairs were generally the only items stored in the luggage compartments.

It was planned to provide a departure schedule board for the terminal; however, it proved to be unnecessary. With the reboarding checks issued, uniformed Fair staff and Greyhound and Trailways dispatchers assisted passengers in locating their buses.

Buses that arrived at the Fair without an advance departure reservation requested a departure slot from the Fair dispatcher who met the bus on arrival

Figure 2. Charter bus terminal.



in the morning. The dispatcher would confirm the slot at the desired hour, if available, or offer the group a choice of the first available time before and after the desired hour. Originally, departures were scheduled only for the hour and half hour. As operating staff gained experience with the terminal, it proved feasible to schedule departures at 15-min intervals.

Several bus companies operated daily charter service (one round trip) daily. These firms were permanently assigned to platform J. Under the reservation system, buses would be allowed to enter the terminal no sooner than 10 min before their scheduled departure time and would have to leave 10 min after the scheduled time. (The 10-min grace period was established to allow for stragglers.) Bus companies were encouraged to write in for departure reservations well in advance, and written confirmations were returned to the companies where time permitted. For touring groups that had, for example, scheduled a meal at a restaurant in the area at a specific time, the ability to receive confirmation of a guaranteed departure time from the Fair was important to the smooth functioning of the tour as a whole.

Staffing Plan

Simulation studies conducted before opening indicated that the transaction time for an incoming bus without an advance departure reservation could exceed 1 min. Bus companies had indicated their preference for a 10:00 a.m. arrival hour (the opening hour for the pavilions and exhibit areas), and it soon became apparent that intensive staffing would be required in the morning hours to prevent bus traffic from queuing up for a mile or more. Greyhound used as many as six dispatchers to handle their traffic on busy mornings; Trailways frequently had four or five dispatchers on their platform. Initial staffing for the Fair-operated portion of the terminal was nine dispatchers and seven traffic controllers. The traffic controllers were positioned at strategic locations within the terminal to direct traffic. Their task was to assign incoming buses to platforms in an efficient manner, to keep the flow of traffic moving, and to ensure pedestrian safety in the terminal. Although the platforms were fenced to prevent passengers from walking between buses when heading for the gate, there was a general tendency to ignore the marked crosswalks and oncoming buses.

After dispatchers and drivers became more familiar with the terminal and the routine, it proved feasible to operate the terminal with a crew of 10 Fair staff in the mornings. Transaction times dropped, thereby making it possible to function effectively with only six or seven dispatchers and three or four traffic controllers.

The evening staffing requirements were substantially lower, requiring only four or five Fair staff once the initial shakedown period was over. These people functioned mainly as traffic controllers, directing the incoming buses to the proper platform, separating pedestrian and vehicular traffic, and expediting the departure of buses when loaded and/or scheduled to depart.

Terminal Capacity

Before the fair opened, the capacity of the terminal was estimated to be 180 buses/h for unloading and 100 buses/h for loading. The figures were calculated on the basis of the bus industry's claims that it took 15-20 min to load a bus and slightly less to unload a full one. Therefore, it was determined that the lot could only turn on a half-hourly schedule for departures, which indicated an hourly capacity of roughly 100 buses. Because arrivals did not have to be scheduled, it was assumed that the turnover would occur approximately 3.5 times/h, allowing for about 180 buses/h on the arrival side.

In practice, the terminal proved able to handle more traffic than predicted. On busy May mornings, once the routine had been perfected and drivers were returning for their second and third trips, it was possible to unload 250 buses/h for a 2- to 3-h morning rush period. In the evenings, in general, the turnover period was shortened to 15 min, which enabled a departure rate of 175-180 buses/h to be achieved when necessary. This was partly due to the promptness of Fair visitors in returning to the terminal at departure times.

Other Features

Several features of the north terminal operation were crucial to its success. One, not previously mentioned, was the stationing of a uniformed police officer at the terminal entrance. This officer, who was hired and paid by the Fair, was responsible for keeping unauthorized vehicles out of the bus terminal--a major problem at some periods of the day--and keeping traffic moving smoothly on the street in front of the terminal. Because several major parking facilities were adjacent to the terminal, this task was substantial.

Discipline was enforced in the terminal, and bus drivers and tour guides came to recognize and respect the need for that discipline. Buses that attempted to linger in the terminal waiting for stragglers past the grace period were requested to leave, although they were permitted to reenter immediately for the next departure time if room was available on that platform (otherwise the bus had to go to a "penalty box" on the street near the terminal to wait for the passengers who were late). A strict no-passing and no backing-up rule was enforced in the platform areas; drivers who violated it were stopped on the spot and informed about the rule. Speeding in the terminal was also cause for swift corrective action. Once drivers understood that passenger safety was paramount, and the necessity for strict safety rules in a terminal handling up to 250 buses and 10 000 passengers/h with no vertical separation of buses and passengers, cooperation was usually obtained. In general, it can be reported that the bus industry exhibited the highest standards of professionalism, working closely with Fair staff to ensure the smooth operation of the terminal and the safety of its users.

Bus platforms were marked with letters on the pavement for the drivers entering the terminal. Signs 2 ft^2 were posted on the ends of each platform for the passengers.

HOTEL AND MOTEL SHUTTLE BUS TERMINAL

The characteristics of shuttle bus operation suggested the need for a terminal design quite different from the charter and tour terminal. Charter and tour buses typically arrived at the Fair only once a day and transported the same group they brought to the Fair. In contrast, shuttle buses returned to the Fair several times a day, and the passengers on an outbound bus were not necessarily the same group that traveled inbound together. Charter buses from a given firm might or might not be using the terminal on successive days; virtually all shuttle services planned to operate each day of the Fair. Hence, while it was not practical to assign permanent loading locations in the charter bus terminal to specific carriers (except for Greyhound, Trailways, and a few regulars with daily departures), it was necessary to assign permanent locations in the shuttle bus terminal so that passengers would know where to find their bus on leaving the Fair, keeping in mind that the outbound bus would be from the same company, but not necessarily the same vehicle, as the inbound one.

Terminal Layout

A location for the shuttle bus terminal was established near the Fair's southwest gate. Again, the principle was that bus passengers would be brought to the gate, but that buses would have to park elsewhere. This was less of an issue for shuttle carriers, since the majority of them were operating several trips with the same piece of equipment and had no desire to leave it near the Fair. The terminal, shown in Figure 3, accommodated 34 buses and 10 vans at a time (note that dark areas are pedestrian terminals). Its layout and location were dictated by land availability and topography. In effect, the terminal was created on land leased by the Fair from the University of Tennessee (UT) adjacent to an existing UT commuter student parking lot. Because the parking lot was to be used by the Fair for revenue parking weekdays from June 10 to September 18 and on all weekends during the run of the Fair, it was desirable to preserve as much of the lot for automobile parking use as possible. As ultimately configured, the terminal combined loading zones all around its perimeter with a minimum-radius turnaround area adjacent to the walkway to the southwest gate of the Fair. (The walkway's purpose was to accomplish a grade change some 20 ft vertically from the terminal to the gates.)

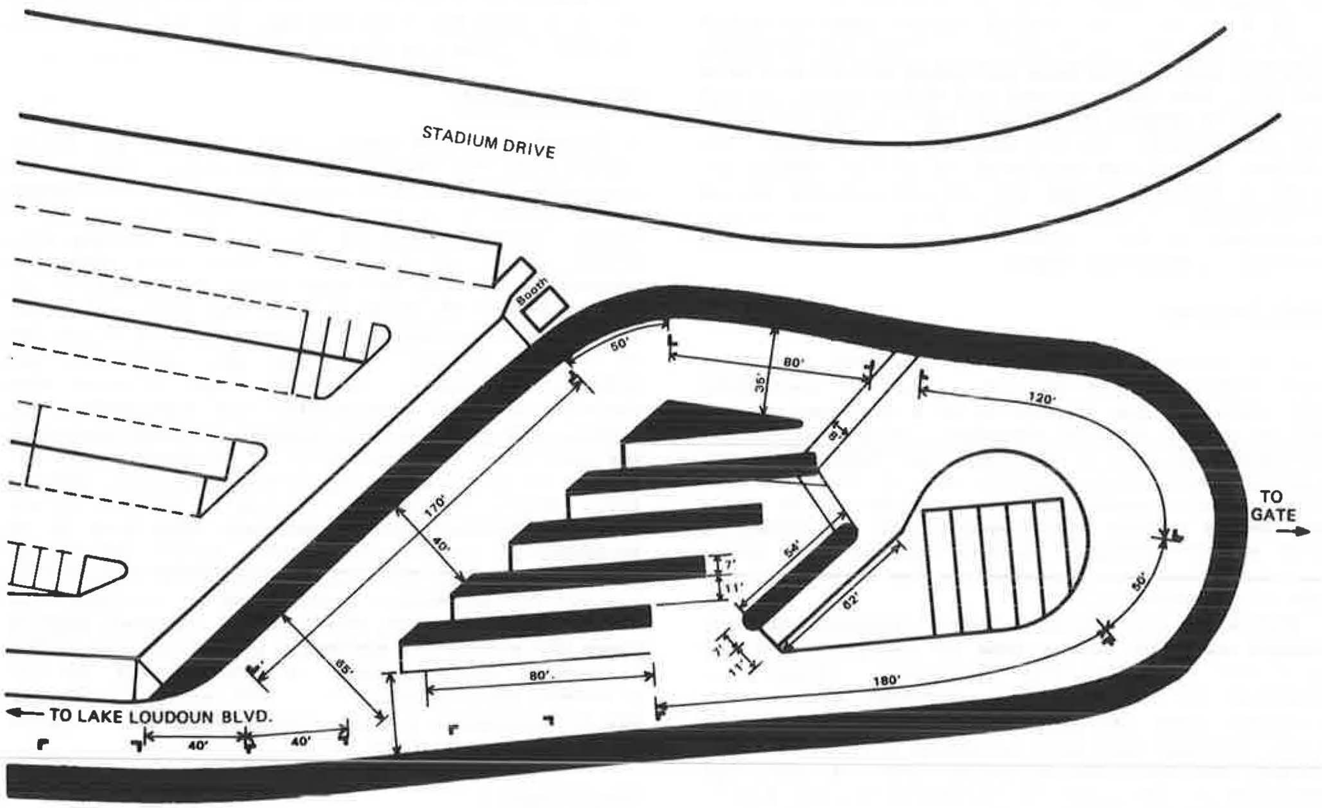
Operating Plan

Shuttle operators were authorized to use the southwest terminal on the basis of individual discussion with Fair transportation services staff pertaining to expected frequency of operation, possible interchange of passengers with other carriers, and other relevant factors. Fair staff assigned carriers to loading positions or zones so as to maximize capacity of the terminal and minimize walking distances. Where several carriers were to use the same loading zone, individual berth use was limited to 4 departures/h. Where the same carrier had routes leaving for various destinations, 6 departures/h were scheduled when necessary. Carriers that indicated that they would be operating more than 6 departures/h were assigned multiple loading berths adequate for their needs.

The terminal layout was based on an operating policy that any bus should be able to pull in, load, and depart without interference from any other bus operated by another carrier. Loading berths were spaced every 40 ft along the south side of the terminal, with 40 ft between berths to allow free movement. These loading berths were grouped into zones, with a given carrier entitled to use any berth within its assigned zone. Fair staff that monitored the terminal prevented carriers from entering the terminal if their loading zone was full and ensured that carriers departed promptly after their allotted layover time when the space was needed for others.

The loading zone and berth operation was only intended for evening use when visitors would be departing the Fair and would need to know exactly where to find their shuttle. For arrivals, the original intent was to have buses unload as close to the gate as possible rather than insisting that all carriers use their assigned berths. Fair staff were to indicate to drivers where to stop and to ensure that a one-bus-length space was left between groups of three or four buses. Four such unloading zones were established. It was estimated before the Fair

Figure 3. Shuttle bus terminal.



opened that, by the time the fourth group of buses had arrived during a busy morning hour, the first group would be ready to leave. Thus, the first unloading zone could be used over again, and buses in the second group could leave while the first group was unloading.

In practice, it proved feasible for the major carriers (those allotted more than one bus length for their loading zone) to use their own zone for morning unloading, and most other carriers preferred to discharge passengers at their loading zone. In that way they could show the passengers just where they would find the bus for the return trip that evening.

Staffing Plan

The southwest terminal was staffed with three Fair dispatchers during the busy hours (4:00-11:00 p.m.) and two at other times. First bus arrivals began at around 8:30 a.m.; last departures varied, with many of the smaller operators making their last run after the nightly fireworks display ended at 10:45 p.m., and some of the larger operators scheduling late departures at 11:30 p.m. or midnight. Inbound passenger and bus volumes peaked between 9:30 and 10:30 a.m.; outbound departures peaked around 6:00-6:30 p.m. and again after the fireworks display (10:30-11:30 p.m.). One dispatcher was stationed at the terminal entrance to allow buses in when their space was available; the others were stationed near the gate to help keep the buses flowing smoothly, answer visitors' questions, and keep pedestrians from walking in the bus lanes. A sheriff's deputy was stationed at the terminal entrance to prevent unauthorized vehicles from entering the lot. (Some charter bus operators attempted to use the southwest terminal and were directed to the north terminal.)

Terminal Capacity

The Fair staff was faced with an apparent imbalance between terminal space supply and demand before the Fair opened. Over 100 applicants for authority to transport passengers to the Fair from points within Tennessee had been heard by the Tennessee Public Service Commission (which had jurisdiction over service outside of the immediate Knoxville area) or the Knoxville Transportation Authority (which had jurisdiction over service from points in Knox County within seven miles from the Knoxville city limits). Virtually all applications that were completely and correctly filled out were granted, and most of those carriers wanted to use the southwest terminal. Many of the carriers had forecasted their ridership on the basis of a 30 percent modal split for their service, with 3.5 persons/hotel or motel room, and thus predicted a daily passenger volume roughly equivalent to one passenger per room served. Fair staff felt confident that the terminal could handle 135 buses/h for loading by using a 15-min turnover for each space, plus more than 60 vans/h. However, the initial carrier projections were for more than 200 bus departures/h. The Fair asked carriers to cooperate during the first few weeks of operation and accept a reasonable share of the available space, with the understanding that a reallocation would occur as carriers changed schedules or withdrew from the market. Dropouts were expected because the total capacity initially offered would have implied a daily ridership of 20 000-30 000 on shuttle buses, which was simply not plausible.

By late July, the terminal was handling 55-60 buses inbound in the morning peak hour (between 9:00 and 10:00 a.m.), which served approximately 1000 passengers/h. The outbound peak occurred between 10:00 and 11:00 p.m., with the same number of buses handling somewhat more passengers. A typical peak half-hour served passenger volumes in the 650-800 range, although on one evening in mid-July the terminal loaded 1400 passengers between 10:30 and 11:00 p.m. on 53 buses. Daily terminal passenger volumes ranged between 3000 and 5000. Van arrivals were not included in these totals.

Other Features

Because of the layout of the loading area, it was possible to use ropes and stanchions for crowd control and pedestrian-vehicle separation in a few locations. However, passengers leaving the Fair and seeing their buses waiting in the center loading islands tended to walk directly across the bus drive. Terminal staff devoted a large portion of their effort in the outbound peak periods to pedestrian control and safety.

An early tendency on the part of some carriers to dispatch more buses during the evening pickup hours than their allocated space could accommodate was solved by direct discussion with the carriers. Major carriers had dispatchers at the terminal and could take swift corrective action. Other carriers were contacted by telephone when necessary. It was generally understood that Fair dispatchers were the final authority in the terminal, and they had the right to bar a carrier's vehicles from the terminal. Fair staff developed the practice of giving the carrier the option of sending the first bus out immediately when an extra bus appeared in the terminal or sending the extra bus out of the terminal to circle the block until space was available. Eventually, carriers were able to adjust their schedule to more closely fit running times and available terminal space as they gained experience with the requirements of their routes. This enabled them to instruct drivers to take layovers at the end of the line away from the Fair or to arrange for en route staging areas and time points. No layover and staging area was provided by the Fair. Each shuttle service was responsible for its own staging areas and schedules.

A number of local school bus operators entered into individual contracts to serve a variety of hotels, motels, parking lots, and campgrounds. Working through the Knox County Bus Owner's Association, they scheduled their own vehicles to avoid conflicts and agreed to use one 2-bus tandem loading location, which operated at much closer headways (as little as 4 min in some cases, according th their original schedules) than the Fair would have scheduled.

The Fair asked all carriers to provide a bus stop sign giving the name of the carrier, the locations served, and the scheduled departure times. These were mounted at the loading zones for passenger information. With only two exceptions, it proved possible to leave carriers in their original loading locations; attrition occurred in a way that seemed to resolve vehicle capacity problems without need for massive relocations.

Several carriers were granted authority to serve the Pigeon Forge-Gatlinburg resort area, approximately a 1-h drive from the Fair. Although there was substantial excess capacity, the carriers were unable to agree on any type of pool service or other arrangement to reduce operating costs while still generating the same amount of revenue. The Public Service Commission chose to allow the rigors of the competitive marketplace to sort out the economics of the situation, and the Fair felt it could not go beyond making suggestions for cooperative ventures.

The alternative to shuttle bus service for many visitors to the Fair was to drive their own cars. Although concrete evidence was lacking, some shuttle operators theorized that first-day visitors would ride the shuttle because they did not know the route to the Fair, the availability of parking, or the severity of traffic problems. Having taken the bus on their first visit and finding parking space available right next to the shuttle bus terminal with no significant traffic congestion, they would drive on subsequent visits. With shuttle fares ranging from $2.75/person for round trips within Knoxville to $6.50 and up (for trips in the 20- to 30-mile range) and $10.00 for the round trip to Gatlinburg, the $6.00 daily parking fee appeared to be a relative bargain to many families, even after including the cost of gasoline. In a sense, the success of other elements of the Fair's transportation system may have created problems for the shuttle operators.

OFFICIAL PARKING LOT SHUTTLE TERMINAL

The Fair provided shuttle bus transportation from those parking lots that were part of the official parking system and were located more than 0.5 mile from the Fair. These routes terminated at an on-street terminal (the Locust Street terminal) a block from the Fair's east gate. A pedestrian overpass was constructed that began at the terminal and ran straight west, crossing Henley Street, to the Fair gate. Two Fair ticket booths were placed at the terminal end of the overpass to reduce congestion at the gate itself. The terminal was originally planned to serve four bus routes, which in turn served five remote parking lots. Lot locations and capacities are given in Table 1. Three of the four routes were planned to load and unload along the west curb of Locust Street; the fourth was to stop westbound on Clinch Avenue. Because street widths precluded long layovers, it was decided that buses would have to unload, load, and leave the terminal without delay, taking layovers at the remote parking lots.

The sidewalk at the Locust Street terminal was occupied by a variety of street furniture; planters and Fair ticket booths took up a significant amount of square footage that might have been needed for pedestrian queuing areas. The pedestrian bridge was only 8 ft wide; it was predicted that several buses unloading in rapid succession could cause the foot traffic on the bridge to back up into the unloading space. During evening hours, a gap in bus service at a time of peak outbound flow from the Fair also could have caused congestion problems.

In fact, a surplus of close-in parking spaces helped prevent the anticipated difficulties from arising. The Coliseum parking garages never handled more than 15 percent of their capacity, and their use as part of the World's Fair parking system ended in July. The other remote lots fared somewhat better, but never realized their full potential. By mid-July, peak-hour bus volumes were down to 18 trips for the three remaining routes, and service was cut back even further in the off-peak afternoon hours, when there might be as few as two trips per hour per route. (Other remote lots, outside the official system, also had problems; a major development of 2500 spaces near the Coliseum garages ceased operation at the end of June.) The capacity of the terminal was challenged only on a few evenings after the fireworks show, when the arrival rate of departing visitors exceeded the available bus capacity for brief periods. The Fair and the shuttle operators ultimately worked out a system for stockpiling capacity near the terminal by shortening headways just before the end of the fireworks and virtually eliminating layovers, thus shortening the round-trip cycle time. This solved the problem.

Table 1. Lot locations and capacities.

Lot Name	Direction from Fair	Capacity (no. of automobiles)	Maximum Peak-Hour Demand (passengers)	Bus Trips per Hour	Avg Automobile Occupancy
Coliseum	East	1850-2350	2140	39	3.80
Willow	East	360	330	6	3.78
Baxter	North	600	330	10	3.65
Martin Hill	South	360	330	10[a]	3.60[a]
Hawthorne	South	230	210		

Note: There were 65 bus trips/h and the average automobile occupancy was 3.75.

[a] Martin Hill and Hawthorne operated as one route (in regard to bus trips per hour and automobile occupancy statistics).

Table 2. Cost factors for terminal operations.

Item	No. and Description
North Terminal–Charter and Tour Bus Operation	
Employees	
Operating labor	15 full-time equivalent
Reservations staff	4 full-time equivalent
Police	2 full-time equivalent
Supervision and overhead	2 full-time equivalent
Total	23 full-time equivalent, for 8:30-12:30 a.m. terminal operation, 7 days/week
Reboarding checks	70 sets of 50 checks, each of 900 numbers
Windshield cards	60 000 for fair dispatcher use only; Greyhound provided own stock and Trailway's did not use them
Printing	400 pages/day of daily log sheet (10 sets, 40 pages each)
	30 000 confirmation copies of reservations
	5000 copies of reservation form and information for operators and groups
Southwest Terminal–Hotel and Motel Shuttle Bus Operation	
Operating labor	6 full-time equivalent
Police	2 full-time equivalent
Supervision and overhead	2 full-time equivalent
Total staff	10 full-time equivalent

The Fair had planned to staff the Locust Street Terminal with a roving inspector, but in fact found this unnecessary. Both shuttle operators provided adequate supervision to ensure proper operation of the lines and the terminal, and the diminished volume of bus traffic eliminated the need for additional staffing. For all practical purposes, the terminal operated much as any downtown multiline bus stop would.

COST FACTORS IN TERMINAL OPERATIONS

As noted above, the short-term nature of the Fair dictated terminal designs and operating plans that were relatively labor intensive with low capital requirements. Table 2 lists the major elements of the terminal operating costs.

In addition to the capital expenditure required for the bus terminals (grading, paving, lighting, and striping), and for crowd-control fences, ropes, and stanchions, a number of minor capital equipment items were found necessary. Both terminals were equipped with bullhorns for crowd control and two-way radios linked to a base station in the Fair's operations center. Low-power walkie-talkies also were used for communications within the terminals to a limited degree. Extensive signing was required to direct passengers to the appropriate platforms in the north bus terminal: approximately thirty 2-ft^2 signs (three per platform) were used to identify the platforms, along with additional signs that carried instructions for bus drivers. The individual bus lines furnished their own signs, which were manufactured to Fair specifications regarding design for the shuttle bus services.

STAFF TRAINING

Two weeks before the Fair opened, the operating staff was on board for training and familiarization with terminal operations. All staff were trained to work both the charter and shuttle bus terminals to enable staff flexibility. Classroom training covered lectures on safety, operation of each of the terminals, procedures for use of two-way radios, and proper traffic-control hand signals. Field training in terminal operations and two-way radio communication was conducted. Because the same personnel would be using the terminal daily, shuttle bus operators were encouraged to participate, with their buses, in the simulation of southwest terminal operations. Arrival and departure operations were enacted and loading and unloading zones were assigned. This was effective in familiarizing shuttle operators with the terminal layout and operation as well as giving the Fair staff hands-on experience before the opening of the Fair.

Simulations of the charter and tour bus terminal operations were conducted by using automobiles and Fair staff employees only, since the majority of bus drivers were long-distance haulers and many would be one-time-only visitors to the Fair. The dispatchers practiced greeting and processing buses with and without departure reservations as well as handling typical inquiries on bus parking locations, group ticket sales, and so on. Simulations were timed to estimate staffing needs and to streamline operations.

CONCLUSIONS

Given the limited land available for terminal operations, the strategy of bringing high-occupancy vehicles directly to terminals at the Fair gates and relying on remote parking areas operated by the private sector worked very well. The passenger volumes handled in the charter and tour bus terminal place that operation well within the top 10 bus terminals in the United States in terms of hourly flow rates. The temporary nature of the facility and the typical visitor's unfamiliarity with the surroundings (as contrasted to a daily commuter terminal) suggest that the labor-intensive design actually expedited passenger flows. It seems fairly clear to those who operated the terminal that a more highly capitalized and automated operation would have functioned at reduced capacity, thereby increasing delays and lowering the number of passengers who could depart at precisely the hour they desired. (Once the initial shakedown period was completed, virtually all departures were accommodated at, or within 15 min of, their desired time.)

The bus industry, once convinced that there was no way to enlarge the terminals, cooperated extremely well in making the terminals function efficiently. Advance discussion with charter, tour, and shuttle bus operators paid off, as their drivers were prepared for what they encountered and did their part to make the system work. The initial tendency of tour operators to cluster their arrivals directly around the 10:00 a.m. opening hour diminished for several reasons: The Fair opened the north gate turnstiles as early as 9:00 a.m. on busy days, thereby enabling early arrivals to be accommodated, and the carriers realized that there was no point in rushing to take their place in a 10:00 a.m.

queue when an 11:00 a.m. arrival could be accommodated without delay on most days.

Unfortunately, it is not possible to generalize from the Knoxville experience about the relative merits of terminals with remote parking areas versus on-site parking. Such an analysis of cost-effectiveness must be site specific. Cost of land and improvements, minor capital item and equipment costs, and operating expenses for alternative configurations are the key variables in the equation, along with the demand to be accommodated. In the present case, the deciding factor turned out to be the unavailability of sufficient land adjacent to the Fair gates to even permit consideration of on-site bus parking. The terminal designs and operating plans used, although born of necessity, proved highly effective and are replicable.

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Assessment of Low-Cost Elevators for Near-Term Application in Transit Stations

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An assessment of low-cost elevators for use in existing transit stations, the supporting data for selecting the screw-column elevator for further evaluation, and an evaluation and assessment of the screw elevator design and operation are presented. This information provides data to authority representatives to enable them to make informed decisions regarding application of the screw-column elevator. The assessment team investigated screw-column elevator design, construction, maintenance costs, and actual use. On-site inspections were conducted at a manufacturing plant and at elevator installations. It was determined that screw-column elevators offer a low-cost alternative for vertically moving elderly and handicapped patrons in transit stations. Low capital expense, minimum time for installation, low cost for standard site preparation, and maintenance costs make the screw-column elevator attractive.

To comply with Section 504 of the Rehabilitation Act of 1973, which states that "no otherwise qualified, handicapped individual shall, solely by reason of his handicap, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving Federal financial assistance," transit authorities must make efforts to provide transportation that handicapped people can use. This may include providing access to existing systems. One element of accessibility is that of vertical movement in rapid transit stations. As past studies have noted, the problems and issues of providing vertical movement accessibility for transit are multifaceted.

To meet the significant problems imposed when locating an elevator in an existing station, the optimal unit will require minimum space, be relatively easy to install, and have an overall low cost. This study analyzed current elevator types to determine which type or types best satisfy these constraints and presents data for the screw-column elevator, which appears to offer important advantages. [The investigation is reported in its entirety elsewhere (1).]

ELEVATOR COMPARISON AND SELECTION

The issues and problems that surround the vertical movement of patrons in transit stations call for certain requirements in the design of an elevator. Issues associated with selecting a unit that will result in an overall low cost and satisfy structural, spatial, and security needs pose design problems for elevators. Each of these problems has been addressed, and a list of important requirements has been developed. These requirements pertain to elevator and station problems generally, but do not attempt to address site-specific problems that face the transit authority and architect or engineer at the time of planning and designing a specific installation.

The following requirements have been identified as necessary to evaluate elevators for transit use. The elevator should

1. Be capable of use by both the elderly and the handicapped and other transit passengers;
2. Have a capacity of no less than 2000 lb;
3. Be sized for wheelchair turnaround, which results in a net car dimension of 80x51 in or 68x51 in, depending on the location of the elevator door opening;
4. Be able to meet the expected vertical rise (nominally 20 ft);
5. Have a low life-cycle cost, which includes capital expense, installation, operations, and maintenance;
6. Be easily installed in existing locations;
7. Provide for passenger safety;
8. Provide for passenger security (such as against malicious attacks);
9. Give reliable service;
10. Meet and satisfy prevailing codes and standards; and
11. Be capable of operating in a transit environment.

These specific requirements set the conditions for any technical analysis of elevators. In addition, for purposes of this report, a nontechnical requirement has been identified: Material should be available that provides information needed by transit authorities to select, purchase, and install elevators that result in the lowest overall cost.

Discussions with manufacturers were conducted and elevator specialists were interviewed to select initial elevator candidates. Five types of elevators were identified and compared with the requirements: conventional electric traction, conventional hydraulic, holeless hydraulic, screw column, and vertical wheelchair platform lift. This comparison is

Table 1. Comparison of elevator and lift types.

Requirement	Conventional Electric Traction	Conventional Hydraulic	Holeless Hydraulic	Screw Column	Vertical Wheelchair Platform Lift
Provide for both elderly and handicapped and other patrons	Yes	Yes	Yes	Yes	No, designed and intended for use by handicapped only
Capacity (2000 lb minimum)	Yes	Yes	Yes	Yes	No, 500-lb nominal capacity
Size (80x51 in or 68x51 in)	Yes	Yes	Yes	Yes	No, nominal size 42x62 in
Vertical rise	Unlimited	Up to 60 ft	Up to 25 ft	Up to 60 ft	Nominal rise up to 10 ft (suitable for level changes within a single room or space)
Cost (total)	Highest	Medium	Low	Low	Lowest
Capital	Highest	Medium	Low	Low	Lowest
Standard installation[a]	Highest	Medium	Low	Low	Lowest
Operation and maintenance	-[b]	-[b]	-[b]	-[b]	-[b]
Retrofit capability	Most difficult due to machine room, pit depth, and heavy structural requirements	Difficult due to need for well hole drilling	Requires limited building modification	Requires limited building modification and no machinery room space	Easily installed
Safety	Safety mechanisms provided in accordance with equipment type	Safety mechanisms provided in accordance with equipment type	Safety mechanisms provided in accordance with equipment type	Safety mechanisms provided in accordance with equipment type	
Security (protection against assault)	Enclosed cars of glass are available; closed-circuit television may be required	Enclosed cars of glass are available; closed-circuit television may be required	Enclosed cars of glass are available; closed-circuit television may be required	Enclosed cars of glass are available; closed-circuit television may be required	Open platform provides good security
Reliability	No specific differences can be identified	No specific differences can be identified	No specific differences can be identified	No specific differences can be identified	
Code satisfaction	Yes	Yes	Yes	Code currently being developed	
Effect of environment on elevator	Environment should affect all units; no perceived difference can be seen between units	Environment should affect all units; no perceived difference can be seen between units	Environment should affect all units; no perceived difference can be seen between units	Environment should affect all units; no perceived difference can be seen between units	Environment should affect all units; no perceived difference can be seen between units

[a] Relative costs could vary due to specific site conditions.
[b] Data available for heavy-use office building environments only.

Table 2. Liaison Board for study of low-cost vertical elevators.

Member	Affiliation
George Wood	Foster Miller Associates, Waltham, Massachusetts
Edward Long	Special Needs Advisory Committee, Boston; and Boston Center for Independent Living
Thomas O'Brien	Massachusetts Bay Transit Authority, Boston
Melvin Sussman	New York City Transit Authority, New York
David Andrus	Port Authority Transit Corporation, Camden, New Jersey
Chris Kalogeras	Chicago Transit Authority, Chicago
Willard Pistler	Greater Cleveland Regional Transit Authority, Cleveland
Max Kroni	General Services Administration, Washington, D.C.
Braja Mahapatra	Southeastern Pennsylvania Transportation Authority, Philadelphia
Michael Tinnirello	Port Authority Trans-Hudson Corporation, Jersey City, New Jersey
George Strakosch	Jaros, Baum, and Bolles, New York
Dennis Cannon	Architectural and Transportation Barriers Compliance Board, Washington, D.C.
Charles Krouse	Professional staff—Committee on Public Works and Transportation, U.S. House of Representatives
M. Ray Whitley	Consulting engineer and chairman of ANSI Ad Hoc Committee on Screw Machine Elevators, Longwood, Florida
Patricia E. Simpich[a]	Project manager, Office of Technology Development and Deployment, UMTA
Theodore Gordon[a]	Senior engineer, American Public Transit Association, Washington, D.C.
Joseph S. Koziol, Jr.[a]	Project engineer, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts

[a] Ex officio member.

given in Table 1. It is assumed, for the comparison, that the site is an existing station that requires a 20-ft rise with openings at two different levels. (A review of the chain hydraulic type mentioned in a related report revealed that it is in the conceptual stage only. It is not immediately available and thus was not reviewed.)

From the data in Table 1 it was determined that

1. Conventional electric traction, due to overall high costs and problems in modifying the existing stations to accommodate the unit, will usually not be the best choice.
2. Conventional hydraulic, although lower in cost than electric traction, offers potential problems in modifying the existing stations to accommodate the unit, especially in the placement of the well hole for the hydraulic jack, and thus will usually not be the best choice.
3. Vertical handicapped platform lifts are strictly limited to transporting individual handicapped persons up or down for very low rises and as

such do not meet requirements. However, these units might be suitable for other, special handicapped-only level changes.

4. Holeless hydraulic and screw-column elevators will usually be the most appropriate types because of the overall lower cost and the fact that station alterations to accommodate their installation are less difficult. These units should therefore be considered the most applicable for vertical movement in existing transit stations.

With the selection of the holeless hydraulic and screw-column elevators as technically applicable elevators, a decision was made, with the assistance of the Low-Cost Vertical Elevator Liaison Board (see Table 2 for a list of members), to consider the additional requirement of this report--the need for information. This consideration was made with the realization that large American manufacturers are actively marketing holeless hydraulic elevators and that applicable information regarding these elevators is available from these manufacturers and consulting engineers. The screw-column elevator, which is considered to be an acceptable alternative, has the additional advantages of no machinery room and limited pit and overhead clearances, is new to the American market, and is currently being sold primarily in Europe; as such, information pertaining to screw-column elevators is limited. The need for information on screw-column elevator installation requirements, operation, and performance was confirmed by the Liaison Board, as it would present another option for transit authorities, with the potential result of lowering the overall cost of elevator installation.

SCREW-COLUMN ELEVATOR DESCRIPTION AND DATA

The screw-column elevator is a direct-drive unit that operates on the screw-lift principle. For elevator installations, a stationary screw-threaded column is located in the hoistway, and a rotating "nut" is driven around the threaded column, which provides the vertical movement. This drive mechanism and principle has been employed on elevators since 1965 in Belgium, where a total of 250 units have been installed by one manufacturer. Only recently have screw-column elevators been introduced to the American market.

This particular elevator has a well-defined market. The primary service for which the elevator is designed is for retrofit installation at relatively low rises. It has proved to be competitive where low rises (within 60 ft), lower capacities (up to 2500 lb), and retrofit installations have been required. The screw-column elevator is not competitive as a high-volume traffic elevator, such as those used in high-rise office buildings, because of the limited rise and also because the travel speed is slower than that of other elevator types.

The screw-column elevator, when compared with other available types, can be seen to have the following advantages and disadvantages.

I. Advantages
  A. It requires less space in the building or structure than other elevator types that have the same capacity, size, and speed (it does not require an overhead machine room like the conventional electric-traction elevator or a machinery room outside the hoistway like conventional and holeless hydraulic elevators; also, lateral space requirements between the elevator car and hoistway are less).
  B. It is usually easier to accommodate in existing buildings and structures than other types of elevators because it requires no machinery room and less space.
  C. It adds less loading to the building and/or structures than do other types of elevators; furthermore, the loading is spread equally over an entire hoistway wall rather than concentrated overhead as with a conventional electric-traction elevator or concentrated at pit level as with a conventional hydraulic elevator.
  D. It has good leveling accuracy with all load variations, which is especially important to persons in wheelchairs and other handicapped users.
  E. It costs less, overall, than conventional electric-traction or conventional hydraulic elevators.
II. Disadvantages
  A. It is designed currently for limited capacity (up to 2500 lb), limited speed, and limited travel installations (rises up to 60 ft).
  B. It has a higher noise level (60 dBA) in the car than do other types of elevators (the motor and drive unit are mounted on the car).
  C. It starts and stops somewhat abruptly.

To obtain the detailed information on screw-column elevators that would be valuable to transit authorities in assessing the applicability in existing transit stations, an assessment team was formed to study and evaluate screw-column elevators. The assessment was made of elevators manufactured by the Ebel Company of Belgium, which has installed more than 250 units.

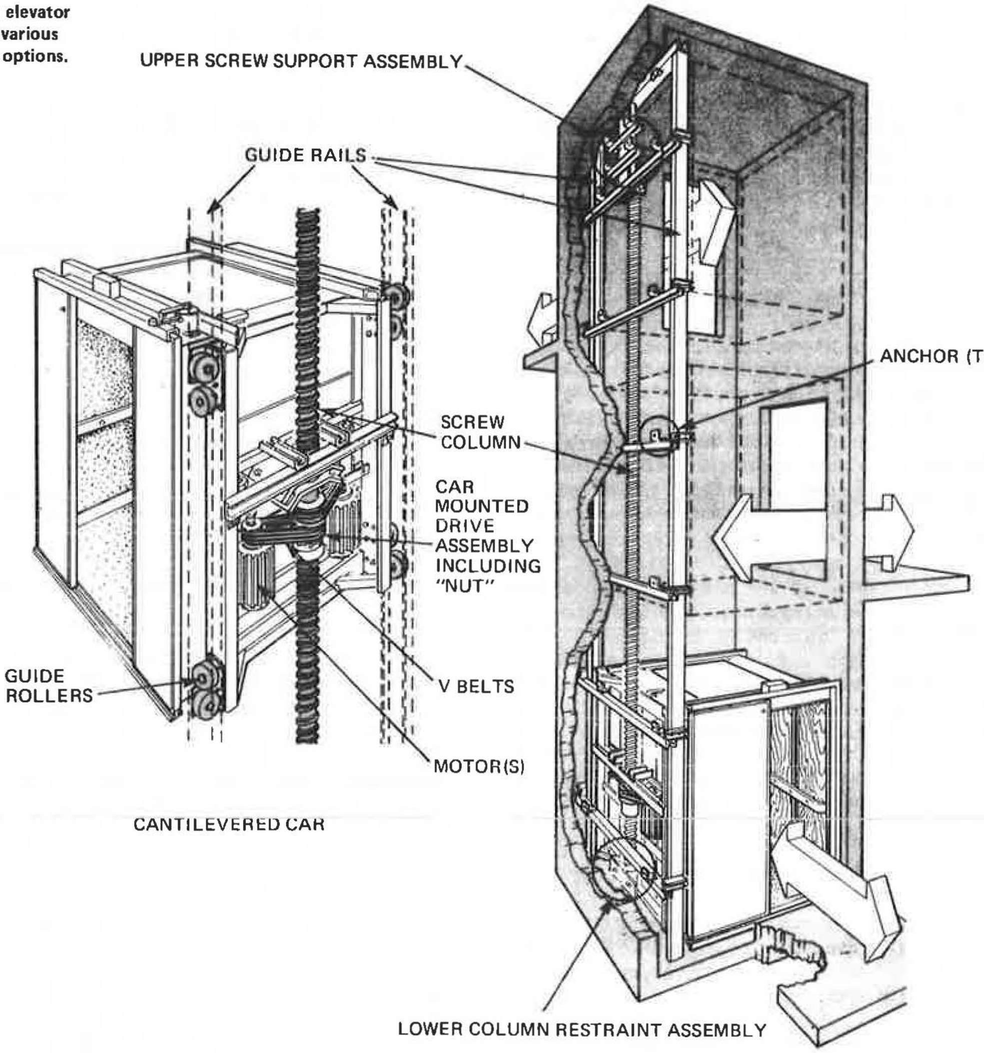
The manufacturer has installed these units in many varied locations, such as warehouses, offices, hospitals, apartment buildings, and private residences. As there is no current Belgium program that requires transit accessibility, no elevators of any type, including screw-column elevators, have been installed in transit locations specifically for handicapped patrons. Evaluation of the elevators took place in the manufacturer's plant plus seven locations in Belgium. These locations were chosen so that the assessment team could obtain a broad picture of the manufacturer's units and gather information that would be most appropriate for transit operation.

The screw-column elevator represents a simple, straightforward, and economical approach to providing basic vertical transportation service. Even with existing limits on capacity, speed, and rise of the unit, it appears to be ideally suited for the movement of handicapped persons in transit stations where large capacities, high speeds, and high rises are not needed.

The screw-column elevator uses a cantilevered car to which the drive mechanism is directly attached. The motor, which is connected to the nut by V-belts, rotates the nut on the stationary screw column and provides the power to move the car both upward and downward. The screw column is supported only from the top and thus is in tension. The belt drive permits desirable slippage should the motor continue to run because of a control malfunction. Movement of the car in the hoistway is stabilized through the use of permanently fixed guide rails.

The relation among the car, hoistway, screw column, drive mechanism, and guide rails, as well as other subcomponents, is shown in Figure 1. As each unit is engineered specially for the site, this manufacturer does not currently maintain detailed specifications or a technical data catalogue of pre-engineered or standard models. However, pertinent typical information for an elevator to be installed

Figure 1. Screw-column elevator schematic, which shows various automatic door opening options.



in a transit station was obtained and is presented below. In addition to the features listed below, the units can be designed for any door location (or with both entry and exit doors) and for various car interiors. All installations to date employ a manually activated swing door, which is the common European practice for small elevators. American standards call for automatic doors. The technical data for a typical transit station installation are given below:

1. Rise: 20 ft (two openings);
2. Rated capacity: 2000 lb;
3. Empty car weight: 775 lb (with no accessories);
4. Add for automatic door: 440 lb;
5. Car door: single slide type, 36-in opening, off center;
6. Car interior: 68x51 in; finished as specified;
7. Leveling tolerance: 0.25 in;
8. Normal velocity: 70 ft/min (approximately);
9. Safety provisions: safety nut and hand lever for manual movement of car;
10. Motor: two at 5 HP, 240 V, 3 ph, and 60 Hz;
11. Brake: internal motor brake, conical type; and
12. Drive mechanism: motor, V-belts, and nut.

FINDINGS AND RECOMMENDATIONS

Screw-column elevators appear to be an acceptable low-cost option for providing vertical movement for elderly and handicapped transit patrons, while providing transit authorities with minimal installation problems at existing transit sites.

Although limited to distribution primarily in Belgium, the market is expanding in various countries, including the United States, for this type of elevator. The manufacturer interviewed is the largest supplier of screw-column elevators and is currently establishing sales and manufacturing in the United States. Rise, Inc., of California is also supplying screw-column elevators and reports that only a few units have been installed in six years. Also, at the same time, code activity is being conducted to provide guidelines for installation and operation of these elevators. Differences between current European practices and anticipated U.S. guidelines are being investigated by the code committee and the manufacturer, and practical solutions are being conceptualized and tested. The manufacturer is committed to the U.S. market, and all units sold in the United States will be manufactured in the manufacturer's stateside facility.

It is the conclusion of this study that, for providing transit authorities with overall low-cost vertical elevators, the advantages of the screw-column elevator far outweigh the disadvantages. Because there is no need for high-capacity, high-speed transport, the primary source of concern is the noise level, which is slightly higher than that of other elevator types. As the patron is subjected to the noise for such a short time, it is considered to be more of an annoyance than a problem. However, the manufacturer is currently attempting to reduce internal car noise levels.

Also, the transit needs, guidelines for accessible design, and customer or patron demands will require modifications to the current design. These modifications may include: (a) provision of power-operated hoistway doors and car doors, (b) larger car size and capacity than the basic minimum elevator provided for handicapped persons in Belgium [1100x1400 mm (43x55 in)], (c) provisions to permit the rescue of persons (possibly severely handicapped) trapped in a stalled elevator by using outside help, (d) emergency voice communication system, (e) specially marked car bin operating panel that can be used by the blind, and (f) possibly an independent governor and safety device if the safety-nut principle used by this manufacturer is not accepted by U.S. code authorities.

It is recommended that, based on the data presented herein and on the observations made from the on-site inspection, a demonstration of screw-column elevators at an existing transit station should be considered. A demonstration will permit data to be collected that will identify how these elevators will perform in a transit environment.

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Park-and-Ride at Shopping Centers: A Quantification of Modal-Shift and Economic Impacts

STEVEN A. SMITH

The purpose of this research was to quantify the effects of park-and-ride facilities at shopping centers on commuter travel and shopping behavior. A survey of commuters at three shopping centers in Montgomery County, Maryland, was conducted to estimate these impacts. The analysis demonstrated that there can be a significant economic benefit to shopping-center operators for allowing commuter parking to occur on their parking lot. Survey results indicate that between 25 and 45 percent of park-and-riders shop at the shopping center on a typical day on their way to or from work. Approximately two-thirds of this shopping activity is either diverted from other shopping locations or in newly induced shopping. For the shopping centers surveyed, the average increase in sales due to the presence of park-and-ride activity is $5/park-and-ride/day. Also, the presence of the park-and-ride facility, in itself, is responsible for 10-30 percent of the park-and-riders choosing to use transit or form a carpool.

Shopping centers have been prime locations for commuter park-and-ride activities for many years. Many such centers and retail sites are located along major public transit corridors and are ideal locations for catching a bus or meeting a carpool. Peak parking demands for shopping centers do not normally coincide with commuter parking peaks, and this creates an opportunity for more effective use of the parking supply. However, shopping-center operators are not generally enthusiastic about commuter parking on their property, perceiving that commuter parking can adversely affect business and the image of the center. In addition, there remain questions about how a park-and-ride lot influences travel behavior, and thus whether these facilities, in themselves, are responsible for including shifts to more efficient modes of travel (i.e., bus and carpool).

Although much of the park-and-ride activity takes place without any formal concurrence from the shopping center, there are also many examples of formal arrangements between shopping centers and local government agencies. This research was designed to quantify the potential benefits of commuter parking to shopping-center operators so that both the engineering community and shopping-center management can make knowledgeable decisions on this issue. Also, it may help the shopping-center management in dealing with problems perceived with informal commuter parking.

STUDY DESIGN

This study was one task of a larger study entitled Parking Policies Study for Montgomery County, Maryland, sponsored by the Maryland-National Capital Park and Planning Commission. Montgomery County is located to the northwest of the Washington, D.C., metropolitan area. It is a rapidly urbanizing suburban county with almost 600 000 residents and an employment of more than 300 000. The study of commuter park-and-ride activity was made to answer the following questions:

1. What modal shifts can be attributed to the presence of a park-and-ride facility at a shopping center? Would commuters simply park in other locations, or is there some actual diversion among alternate modes of travel?
2. What are the economic benefits of commuter parking to shopping-center operators?
3. Does the patronage of the shopping center by commuters divert shopping trips from a peak to an off-peak period, possibly justifying reductions in parking requirements for those centers that permit commuter parking?

To answer these questions, a survey was designed to question commuters on their travel and shopping habits at three commuter park-and-ride lots in Montgomery County. The three locations were Montgomery Mall, Wheaton Plaza, and Aspen Hill Shopping Center. Both Montgomery Mall and Wheaton Plaza are regional shopping malls and are formally designated as park-and-ride lots by the Montgomery County Department of Transportation. The Aspen Hill center serves as an informal, but heavily used, facility, and has nearly 200 commuter vehicles parked on the lot. It contains a major grocery store, drug store, and clothing store as well as a variety of smaller shops. The commuters consumed approximately 20 percent of the Aspen Hill center's parking capacity but did not affect parking availability for other shoppers. The Montgomery Mall and Wheaton Plaza lots accommodated 460 and 320 vehicles, respectively, on the days of the survey in early November 1981, which was slightly less than 10 percent of the parking supply. Walking distances to the stores from the commuter parking locations were as follows: Montgomery Mall, 300-500 ft; Wheaton Plaza, 500 ft; and Aspen Hill, 100-300 ft. The shopping centers range between 9 and 14 miles from downtown Washington.

Surveys were conducted in favorable weather conditions on typical commuting days between 6:30 and 9:00 a.m. Interviews were conducted as persons who park at the lot exited their vehicle to form a carpool or catch a bus. Usually the interviews were conducted orally, but in some cases the questionnaire was given to the park-and-rider to be filled out while waiting either for the bus or other carpool members. In other instances, a questionnaire and mailer were handed to the respondent with the hope that it would be returned. The questionnaire used is given below:

1. How often do you park here?
   a. Usually 5 days a week
   b. 3-4 days a week
   c. 1-2 days a week
   d. Less than that
2. Do you normally park here to:
   a. Catch a bus?
   b. Meet a carpool?
   c. Other (specify)
3. Did you park here yesterday?
   a. Yes
   b. No
   (If no, skip to question 8)
4. If the lot had not been here, what would you have done to get to work yesterday?
   a. Would have parked nearby (within walking distance) and caught the same bus or carpool
   b. Would have caught the bus or met the carpool somewhere else
   c. Would have driven all the way to work
   d. Other (specify)
5. Did you shop at any of the stores here yesterday on your way to or from work?
   a. Yes
   b. No
   (If no, skip to question 8)
6. About how much did you spend?
7. If this lot had not been here, what would you have done about obtaining yesterday's purchases?
   a. Bought the same things at this location on the way to or from work
   b. Bought the same things at this location at a different time (list probable day and time as best you can)
   c. Bought the same things at a different location (list probable day and time as best you can)
   d. Not bought the things
   e. Other (specify)
8. In a typical week, how often do you shop at these stores when you park here for your trip to work?
9. In a typical week, how much do you spend when you park here for your trip to work?

An excellent response was achieved from the surveys at each of the sites, with 50-60 percent of all park-and-riders in the lot during the survey day responding. Many of those interviewed were quite suspicious of the objective of the survey, some being fearful that the lot could be disbanded as a fringe facility. Although this could have resulted in some dishonest responses, it was felt that the face-to-face interview methodology, which required quick thinking on the respondents' part, combined with the specificity of most of the questions (e.g., "Did you shop here yesterday?") minimized such bias. If bias exists, one would probably expect it to occur more with the questionnaires mailed back, because those respondents would have had more time to contrive false answers. However, the comparison of the mail-backs with the personal interviews for several key questions indicated that little bias existed. The mail-backs, which comprised only 10 percent of the returns, were therefore combined with the other returns. In all, the following number of completed questionnaires were received: Aspen Hill, 112; Montgomery Mall, 256; and Wheaton Plaza, 147.

RESULTS

Travel and Use Characteristics

The table below (in response to Question 1) indicates that, at each shopping center, at least 65 percent of the commuters reported using the lot for park-and-ride usually 5 days/week. [Ed. note: For the following tables, the left column (a., b., c., and so on) refers to the choices given under each of the questions in the survey. Please refer back to the questionnaire for explanations of the responses.]

	Aspen Hill		Montgomery Mall		Wheaton Plaza	
Frequency	No.	Percent	No.	Percent	No.	Percent
a.	76	68	185	72	97	66
b.	16	14	43	17	23	16
c.	12	11	12	5	16	11
d.	8	7	15	6	11	7
Total	112		225		147	

Including those who use the lot on the average of 3-4 days/week brings the total figure of regular use to between 82 and 92 percent. The table below shows that most (between 74 and 94 percent) are using the lot to catch buses as opposed to using it for carpool or vanpool formation (responses to Question 2):

	Aspen Hill		Montgomery Mall		Wheaton Plaza	
Purpose	No.	Percent	No.	Percent	No.	Percent
a.	82	74	241	94	118	84
b.	28	25	7	3	19	13
c.	1	1	8	3	4	3
Total	111		256		141	

The table below indicates the responses to the hypothetical question of what the park-and-rider would have done to get to work had the park-and-ride lot not existed (responses to Question 4):

	Aspen Hill		Montgomery Mall		Wheaton Plaza	
Alternate Trip Choice	No.	Percent	No.	Percent	No.	Percent
a.	30	34	79	35	16	14
b.	35	40	34	15	77	68
c.	11	13	64	29	12	11
d.	12	13	46	21	8	7
Total	88		223		113	

Although the question was hypothetical, experience with that line of questioning revealed that people could fairly readily formulate an alternative. Other than a before-and-after analysis of travel patterns at a recently instituted or removed park-and-ride lot, this is the only way to estimate the modal shift induced by the park-and-ride facility itself (i.e., exclusive of other factors that induce people to park-and-ride).

Both Aspen Hill and Wheaton Plaza are situated near a multitude of other retail uses while Montgomery Mall is relatively isolated from other sources of parking. For the former two, between 74 and 82 percent would have caught the same bus or carpool. In the case of Montgomery Mall, up to 30 percent may have chosen to drive all the way to work, but only about 10 percent in the cases of Aspen Hill and Wheaton Plaza. The relative isolation of Montgomery Mall may have contributed to the more significant levels of diversion. Thus, the provision of park-and-ride lots may divert a percentage from single-occupant automobile trips, but many would still find some other informal park-and-ride arrangements.

Shopping-Center Patronage by Park-and-Riders

The table below indicates the proportion of those who parked at the fringe lot the day prior to the interview and who also shopped at the shopping center on the way to or from work (responses to Question 5):

Shop Here	Aspen Hill		Montgomery Mall		Wheaton Plaza	
Yesterday?	No.	Percent	No.	Percent	No.	Percent
Yes	40	44	94	42	28	25
No	50	56	129	58	83	75
Total	90		223		111	

The highest percentage was Aspen Hill at 44 percent and the lowest was Wheaton Plaza at 25 percent. Aspen Hill is a smaller facility with parking located closer to the stores. This combined with the type of stores (grocery and drug store as primary tenants) may explain why Aspen Hill had the highest shopping frequency. The park-and-ride lot area was farthest away from the shopping facilities at Wheaton Plaza, which possibly explains the less-frequent shopping there.

In a question related to the above table ["About how much did you spend?" (answered only by those who shopped at the center yesterday)], the average purchases were as follows: Aspen Hill, $14.10; Montgomery Mall, $25.56; and Wheaton Plaza, $16.30. One could compute the average daily purchase amounts per fringe lot user by multiplying the dollar values above by the percentage of those shopping at the center yesterday. These amounts are as follows: Aspen Hill, $6.20; Montgomery Mall, $10.61; and Wheaton Plaza, $4.08.

To determine the true increase in purchases brought about by the existence of fringe parking, one must also identify what the commuters would have done about their purchase had they not been able to park all day at the fringe lot. It is possible that many of the purchases may have been made at the same center anyway, in which case the actual benefit to the shopping center operator is reduced.

The table below indicates what those commuters who had made purchases yesterday would have done in the absence of the fringe lot (responses to Question 7):

Alternate Purchase	Aspen Hill		Montgomery Mall		Wheaton Plaza	
Preferences	No.	Percent	No.	Percent	No.	Percent
a.	8	24	7	8	4	12
b.	1	3	14	15	4	12
c.	20	61	53	55	14	45
d.	4	12	17	18	7	22
e.	0	0	4	4	3	9
Total	33		95		32	

Between 8 and 24 percent said they would have stopped by on the way to or from work anyway. A relatively small percentage (3-15 percent) said they would have come back to that same location at a different time. The largest proportion--the majority in two cases--would have bought the things at a different location. Respondents indicated that typical alternatives would include other shopping centers near home or stores close to the work place. A significant percentage (12-22 percent) stated they would not have made the purchases and thus could be labeled as induced shopping. The percentage of yesterday's shopping trips that could be legitimately claimed as an increment caused by the presence of the fringe lot would be the sum of the percentages of items not bought and items bought at a different location. These would be: Aspen Hill, 73 percent; Montgomery Mall, 73 percent; and Wheaton Plaza, 67 percent.

Applying the above percentages to the average daily purchase of a fringe parker yields the incremental average daily purchase per parker that could be attributed to the presence of the fringe lot: Aspen Hill, $4.53; Montgomery Mall, $7.75; and Wheaton Plaza, $2.73. In other words, the decision by the shopping-center operator to allow commuters to use the parking lot would increase daily shopping-center sales by the above amounts for each commuter that uses the lot. The average of the three locations is about $5/day. Thus, 100 daily parkers could add $500 to the center's daily sales or $120 000 over the course of the year (weekends and holidays excluded). For a smaller center such as Aspen Hill, the 200 commuters parking at the lot would represent an increase in sales of approximately 2 percent. For the larger centers, an increase of 0.5-1 percent would be typical. The sales increases would be most significant at convenience-type stores, especially grocery and drug stores. Earnings are significantly greater than the incremental cost of maintaining the parking spaces set aside for commuters.

As a check on the validity of some of the responses, particularly the average purchase amounts, two additional questions were asked about typical weekly shopping habits. The table below indicates that a small minority never shop at the center on the way to or from work and the majority shop 1-2 days/week (responses to Question 8):

Frequency of Shopping (days	Aspen Hill		Montgomery Mall		Wheaton Plaza	
per week)	No.	Percent	No.	Percent	No.	Percent
Usually 5	5	5	3	1	2	2
3-4	32	29	33	15	15	11
1-2	50	46	151	66	73	55
<1	11	10	29	13	13	10
Never	11	10	12	5	30	22
Total	109		228		133	

The mean frequency of shopping ranges between 1.3 days/week at Wheaton Plaza to 2.0 at Aspen Hill.

Table 1. Alternate times of purchase had the fringe lot not existed.

Alternate Times	No of Responses			Total	
	Aspen Hill	Montgomery Mall	Wheaton Plaza	No.	Percent
Buy at this location					
Weekday					
Morning	0	1	0	1	8
Evening					
12:00-4:00 p.m.	0	0	0	0	0
4:00-6:00 p.m.	0	0	1	1	8
After 6:00 p.m.	0	0	0	0	0
Time uncertain	0	0	0	0	0
Weekend					
Morning	0	5	1	6	46
Evening					
12:00-4:00 p.m.	0	3	2	5	38
After 4:00 p.m.	0	0	0	0	0
Total	0	9	4	13	100
Buy at other location					
Weekday					
Morning	0	0	0	0	0
Evening					
12:00-4:00 p.m.	0	7	0	7	16
4:00-6:00 p.m.	2	8	1	11	25
After 6:00 p.m.	6	5	2	13	30
Time uncertain	2	0	0	2	5
Weekend					
Morning	2	6	0	8	19
Evening					
12:00-4:00 p.m.	0	0	0	0	0
After 4:00 p.m.	0	0	0	0	0
Time uncertain	1	0	1	2	5
Total	13	26	4	42	100

Dividing the mean by 5 days/week should yield a value close to the percentage of fringe parkers who shopped at the stores yesterday. Remarkably, these values differ by only 1-2 percent for Aspen Hill and Wheaton Plaza and 10 percent for Montgomery Mall.

Likewise, the weekly purchase amount shown in the table below should roughly agree with the average weekly purchase amount computed from the "yesterday's trip" statistics (responses to Question 9):

Item	Purchase ($)		
	Aspen Hill	Montgomery Mall	Wheaton Plaza
Avg weekly purchase	25.13	28.27	19.28
Weekly purchase computed from "yesterday's trip" statistics	31.00	53.05	20.40

In each case, the amount specified from Question 9 was higher than the amount computed from "yesterday's trip" statistics. Except for Montgomery Mall, however, the difference is less than 25 percent, which is a relatively close agreement considering the subjective nature of the question.

The above results are somewhat similar to another study at four suburban shopping centers, which found that only 6 percent of the commuters who parked at the lots did no shopping at the centers. Nearly a quarter of the commuters spent more than $35/week at the centers, while more than 40 percent spend $1-$10/week at the centers (1). If there is any loss of other business because of the presence of the commuters (e.g., making it less convenient for other shoppers), this would reduce the net benefit.

Displacement of Peak Shopping Trips

A possible additional benefit of the fringe lot to shopping centers is the displacement of trips from the peak parking time (typically Saturday afternoons) to a period of less demand. This could conceivably justify a reduction in the parking requirements for centers that allow commuter parking, which results in an economic savings in construction of parking if such displacement is significant.

This hypothesis was tested by asking those who made purchases yesterday when they would have made them had the lot not existed. As could be imagined, the very hypothetical nature of this question made it difficult to answer concretely, and some people could not adequately respond. Of those that did respond, Table 1 summarizes the findings. For those that would have bought the things at the same location (only 13 samples), 84 percent would have made the purchases on the weekend (typically Saturday). Nearly 40 percent would have gone in the afternoon, which coincides with the peak parking time. This represents only about 1 percent of all the commuters surveyed, however.

For those who would have bought the items at a different location, 75 percent would have made the purchase on a weekday, according to the time distribution shown in Table 1. Purchases between 12:00 and 4:00 p.m. (16 percent) would be primarily near the work location, and those after 4:00 p.m. would probably tend to be at different shopping centers near the home. It is apparent, however, that any diversion of shopping trips from the peak shopping period is quite small, and a reduction in the number of parking spaces required based on the initial hypothesis cannot be justified.

SUMMARY

The analysis demonstrated that there can be a significant economic benefit to shopping-center operators for allowing commuter parking to occur on their parking lot. Survey results indicate that between 25 and 45 percent of park-and-riders shop at the shopping center on a typical day on their way to or from work. Approximately two-thirds of this shopping activity is either diverted from other shopping locations or is newly induced shopping. For the shopping centers surveyed, the average increase in sales due to the presence of park-and-ride activity is $5/park-and-rider/day. Also, the presence of the park-and-ride facility, in itself, is responsible for 10-30 percent of the park-and-riders choosing transit or carpooling.

Designating a portion of a parking lot for park-and-riders will be most attractive for convenience-type shopping centers and for locations along radial arterial streets. The percentage increase in sales will be greatest for smaller centers as long as no parking capacity problems are created. Although the economic benefits to shopping-center operators will vary by location, type, and size of center, public agencies should consider soliciting the cooperation of shopping-center operators in establishing park-and-ride facilities. Benefits will be derived (a) by the shopping-center operator as long as there is an adequate parking supply for all customers, (b) by the commuter in that work and shopping trips are more easily linked, and (c) by the public agency in reduced need for additional parking facilities and in reduced vehicle travel.

ACKNOWLEDGMENT

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Potential and Cost of Commuter or Regional Rail Service

E.L. TENNYSON

For approximately 100 years, railroads have carried commuting passengers between home and work in nine major metropolitan areas in the United States and Canada. These operations, with one exception, have demonstrated a stability of patronage not usually present in public transit by highway. In more recent years, Toronto has instituted a new, successful, and growing commuter or regional railway system, which indicates that the potential for such service is contemporary as well as traditional. Currently, fuel consumption and currency inflation are two of the most serious national problems. Highway traffic problems are closely related. At least in theory, commuter or regional rail service can mitigate all three of the adverse effects to the mutual benefit of all concerned. The potential usefulness of such commuter or regional rail service is analyzed to determine the demographic characteristics that contribute to its effectiveness. The results are reviewed to test the viability of commuter or regional rail service in other possible areas—either additional corridors in the 10 metropolitan areas currently served or new services to cities served only by highway transit. The possible reduction in federal transit operating assistance and the ever-present need for cost-effectiveness in urban public transit require rigorous cost analysis and economic advantage to justify any commitment to new or expanded service. Labor, energy, and other cost factors are analyzed to determine the potential economic viability of such rail service vis-à-vis other transit alternatives.

Urban transportation of passengers can be provided by highway or railway. Air travel is much too energy intensive and expensive for short trips and would be physically impractical in central business districts (CBDs) without ground transportation to support it. Water transportation is not possible for most urban areas and, although still useful in unique circumstances, this mode has been abandoned as impractical in most of those cities that used it in the past.

In most cases, the primary alternatives for effective urban transportation are highway and rail. All highways function together as a single ubiquitous system, but rail transit is divided into three physically similar but institutionally different types of service and operation:

1. Heavy rail rapid transit, which is incapable of street operations;
2. Light rail, or street railway, which is best used off-street; and
3. Regional or commuter rail, which uses freight railroad track.

Regional or commuter rail passenger service is superficially the easiest to implement because it can, where feasible, use existing rights-of-way coincident with other rail activity.

The efficiency of rail rapid transit would usually commend it for all urban rail passenger service, except for the high installation cost and the requirement for high volumes of travel. Regional or commuter rail is used to avoid the high capital cost of rail rapid transit and attendant requirements for high-volume travel. Light rail can be used in place of commuter rail where freight and intercity passenger movements can be relegated to off-peak or middle-of-the-night hours. Regional or commuter rail service is most appropriate for existing suburban trackage with modest travel volumes, at least at the outer extremities.

Commuter or regional rail service is well worth consideration where it can offer faster travel than city transit service (approaching automobile competitive speeds), where it costs less to provide than automobile travel plus parking, and where it removes more than 600 passengers/peak hour (one-way) from congested streets, thus creating the equivalent of an additional traffic lane without the cost.

INVENTORY OF SERVICES

To study and evaluate the usefulness and viability of regional rail service, existing services are reviewed herein to develop their characteristics. Table 1 (1-3) delineates the regional rail routes in the United States and Canada, grouped by operator in their respective metropolitan areas. Some of the data are a bit arbitrary, as some passengers and mileage are common to more than one line or route, but the representation is generally valid.

MODES

Regional rail service is operated in four different modes, which can be combined practically into eight alternatives:

1. Conventional train operation with locomotives,
2. Locomotive-powered trains in push-pull operation,
3. Diesel self-propelled cars or trains operated without locomotives, and
4. Electric multiple-unit train operation (without locomotives).

All four modes serve passengers quite similarly, except that electric multiple-unit trains offer much faster service. It is also a more economical service for frequent operation. Otherwise, the difference among modes is largely technical, but with economic variations.

The push-pull mode is most efficient in simple point-to-point operation, particularly if two cab-control cars are employed per train to permit dropping unneeded cars during the off peak. The cab-control car enables the engineman to operate from the lead car, with the locomotive pushing the train from the rear. This avoids the necessity for turning the train at terminals. The disadvantages of push-pull operation are its loss of acceleration in peak hours with heavier trains and its loss of flexibility in shifting cars between trains to maximize peak car utilization.

The locomotive-drawn train without the push-pull feature requires inconvenient and costly yard switching operations at each end of each trip throughout the day in order to keep the locomotive on the front of the train. It is not recommended for large or frequent service operation because of these problems.

Diesel self-propelled cars are flexible in their operating pattern and offer better acceleration than a longer locomotive-powered train, without the cost of a locomotive. However, the many engines that require service and maintenance make them uneconomical for longer trains. The high cost and lower

Table 1. Commuter rail routes in the United States and Canada.

Commuter Rail Route	Line Length (miles)	Cars	Weekday Passengers
Boston: Boston and Maine Railroad			
Attleboro	32		2 470
Ayer	36		4 515
Framingham	21		1 560
Franklin	28		1 560
Hamilton-Wenham	23		3 270
Haverhill	33		7 380
Lowell	26		8 925
Rockport	35		3 265
Stoughton	19		990
Total	253	232	33 935
Chicago			
National Railroad Passenger Corp. (Amtrak): Valparaiso	44	10	900
Burlington Northern: Aurora	38	141	47 000
Chicago and Northwestern			
Geneva	36		25 560
Harvard	63		36 125
Kenosha	52		27 315
Total	151	307	89 000
Chicago, Milwaukee, St. Paul and Pacific			
Elgin	37		11 500
Walworth	74		12 500
Total	111	128	24 000
Illinois Central Gulf			
Blue Island	18		13 000
Joliet	38		800
Park Forest	30		39 000
South Chicago	12		26 000
Total	98	173	78 800
Norfolk and Western: Orland Park	23	15	1 850
Northeastern Illinois Regional Commuter Railroad Corp.			
Blue Island	16		18 120
Joliet	39		7 880
Total	55	89	26 000
Chicago South Shore and South Bend: South Bend	74	46	9 000
Chicago area total	594	909	276 550
Detroit Grand Trunk Western: Pontiac	26	30	1 500
Montreal			
Canadian National (CN)			
Cartierville	8		4 000
Duex Montagnes	29		4 035
Ste. Hilaire	21		400
Total	58	64	8 435
Canadian Pacific (CP)			
Farnham	43		300
Rigaud	40		6 000
Ste. Therese	26		250
Total	109	49	6 550
Montreal area total	167	113	14 985
New York			
Metropolitan Transit Authority			
Dover Plains	77		65 165
New Caanan[a]	41		6 000
New Haven[a]	73		55 170
Poughkeepsie	72		57 165
Total	263	766	183 500
Long Island Railroad			
Babylon	38		40 290
Brooklyn	9		61 265
Far Rockaway	23		23 305
Greenport	96		11 155
Hempstead	22		27 935
Long Beach	25		23 070
Long Island City	9		9 490
Montauk	117		6 625
Oyster Bay	35		10 720
Port Jefferson	59		32 460
Port Washington	20		32 795
West Hempstead	22		9 490
Total	275	1011	288 600
New Jersey: New Jersey Transit			
Bergen County	23		12 000
Boonton-Netcong	48		12 000
Gladstone	42		10 000
Montclair	12		1 500
Morris and Essex	35		30 000
North Jersey Coast	67		15 000
Pascack Valley	31		9 000
Port Jervis via Paterson	87		12 000
Princeton	2.5		1 000
Raritan Valley	67		10 000
Trenton (Amtrak line)	58		27 500
Total	472.5	973	140 000
New York area total	1010.5	2750	612 100
Pittsburgh			
Pittsburgh and Lake Erie: Beaver Falls	30	5	420
Baltimore and Ohio: Versailles	18	10	1 780
Pittsburgh area total	48	15	2 200
Philadelphia: Southeastern Pennsylvania Transportation Authority			
Chestnut Hill East	11		6 100
Chestnut Hill West	12		9 000
Doylestown	35		11 500
Fox Chase	11		6 300
Ivy Ridge-Manayunk	9		1 300
Norristown	18		3 600
Paoli-Downingtown	31		22 000
Trenton (Amtrak)	33		7 200
Warminster	20		5 000
West Chester-Media	28		15 000
West Trenton	33		6 750
Wilmington (Amtrak)	27		10 000
Total	68	402	103 750
San Francisco: Southern Pacific: San Jose	47	83	22 150
Toronto: Government of Ontario Transit			
Georgetown (CN)	29		4 000
Hamilton (CN)	39		17 435
Milton (CP)	33		3 500
Pickering (CN)	22		17 435
Richmond Hill (CN)	21		2 900
Toronto area total	144	221	45 270
Washington, D.C.			
Amtrak: Baltimore	40	10	1 200
Baltimore and Ohio			
Baltimore	37	10	1 350
Martinsburg	73	22	3 500
Total	110	32	4 850
Washington area total	150	42	6 050
Total U.S. and Canada	2707.5	4797	1 118 490

[a] Connecticut Transit Authority.

acceleration (than electric cars) should be considered in detail before any attempt is made to avoid electrification. Speed is a necessity as well as a two-way advantage. Speed attracts ridership more than any other single factor (other than the service itself) and augments revenue that helps to sustain the service. Speed also offers the opportunity on busy lines to reduce fleet investment and crew cost, as a single train can make more productive trips per day.

ALTERNATIVES

The following eight alternatives are derived from the list of modes given above:

1. Conventional trains (1);
2. Push-pull trains (2);
3. Self-propelled diesel trains (3);
4. Electric multiple-unit trains (4);
5. Self-propelled diesel trains, supplemented in peak hours with conventional trains (3 and 1);
6. Self-propelled diesel trains, supplemented in peak hours with push-pull trains (3 and 2);
7. Electric multiple-unit trains, supplemented in peak hours with express diesel locomotive trains (4 and 1); and
8. Electric multiple-unit trains, supplemented in peak hours with electric locomotive-powered trains (4 and 1 or 4 and 2).

Electric operation offers faster service than diesel and is free of any dependence on foreign relations for fuel supply. It also provides a more efficient alternative for short-train operation if multiple-unit cars are used. Electric operation is subject to high power demand charges, however, which suggests the use of diesel locomotives on the longest trains in peak hours that operate express over a portion of the route to minimize acceleration losses. If demand charges for power are reasonable, electric locomotives should be used to speed up service and reduce maintenance costs. The best rail horsepower attainable from a standard diesel locomotive is 2400 (1800 kW), but a straight electric can produce more than twice that, thereby greatly reducing locomotive maintanance costs. Electric locomotives, however, lack the necessary adhesion to equal multiple-unit car performance with long trains.

RESULTS

As highways have been improved and freeways constructed into CBDs, automobile travel has increased markedly in urban areas. At the same time, local street transit has languished at its 1895 schedule speed of approximately 10 mph (4, Codes 2004, 3019, 5031, 6032, 9015, p. 2-196). Suburban express lines may exceed 15 mph, but this is hardly competitive with automobile operation, even on congested freeways. Regional rail service is an exception to this limitation. Speeds range upward from 20 mph to in excess of 40 mph.

Population growth in metropolitan areas between 1927 and 1972 did not increase urban transit travel. Except for the period of gasoline and tire rationing between 1942 and 1946, urban transit travel fell sharply from 70 million passengers per weekday to a mere 20 million--a loss of 72 percent in the absolute and 85 percent per capita. Suburban transit losses were even greater on a per capita basis (5, Table 9, p. 52; Table 11, p. 55; 6).

As the result of this precipitous decline, small cities no longer have the traffic base to support viable urban transit in any form. Larger cities need higher transit speeds to win back lost riders; reduce congestion, energy, and inflationary problems; and improve center-city accessibility.

Federal aid to highways began in 1914 and reached a high level with the passage of the Interstate Highway Act in 1955. The resultant free highway system was far too strong a factor against which private capital in public transit could not effectively compete. Only with federal aid to urban transit in 1964 did transit begin to modernize effectively by building new facilities capable of scheduled speeds of 20-30 mph.

Because regional commuter railroads were not usually a corporate part of urban transit systems, they were often ignored in transit planning and funding, much to the disadvantage of all concerned. Philadelphia recognized this mistake in 1955 and tried to correct it. The state of New York bought the Long Island Railroad for the same reason. The government of Ontario undertook to provide a new commuter rail service in 1967, and now Chicago's Regional Transportation Authority has actually undertaken commuter train operation. California has contracted for San Francisco Peninsula commuter train service and for a new service from Los Angeles to Oxnard. The Southeastern Michigan Transportation Authority has assumed responsibility for commuter rail service in the Detroit area. The Massachusetts Bay Transportation Authority (MBTA) has followed the same course, and now (1983) New Jersey and Pennsylvania are undertaking actual operation of regional rail service in the Northeast Corridor, Hoboken, and Philadelphia areas.

The reasons Philadelphia began this trend, and other areas have followed, are threefold:

1. Regional rail travel did not decline as highway transit declined. The superior speed, comfort, and reliability of rail travel held most of its patronage despite increased automobile competition on new freeways. Only in cases of total rail abandonment did rail travel decline markedly. Growth in train travel was evident on other lines, although highway transit continued to decline (5,6).
2. Highway congestion was becoming intolerable in certain urban areas, with attendant undesirable side effects. A previous street railway line may have carried 8000 one-way passengers per peak hour on a major artery in 1944, but the return to unrationed motor fuel for automobiles in 1947 hampered the free movement of streetcars (and buses) and accentuated the switch from transit to automobile. The problem was that where street cars carried 8000 passengers/h in a single lane, albeit slowly, the switch of 4000 of these riders to faster automobiles required another seven highway lanes, which were simply not available in the highly concentrated center city. The switch also required costly parking facilities. These two factors drove businesses to the suburbs, where open land was available with sewer subsidies along new freeways, which facilitated automobile access, but not transit. Then the open land filled up with low-density urban sprawl, and congestion moved to the suburbs.
3. CBDs depend on accessibility for viability. Highways alone cannot provide the necessary accessibility for lack of capacity, whereas regional rail service can, as can rapid transit.

These considerations have necessitated the continuance of regional rail service. Where properly applied, it is by far the most efficient and cost-effective mode of public transportation when ridership generation and capital cost, as well as operating costs, are considered. The usual three-person multiple-unit train crew on four cars (peak) will typically produce 15 000 passenger miles of travel

Table 2. Metropolitan areas with regional (commuter) rail potential.

Area	Population[a]	Activity Factor[b]	General Riding Habit[c]	Percentage of Population Riding[d]	Weekday Passengers[e]	Cars Required[f]	No. of Possible Lines[g]
Los Angeles[h]	8 351 266	708	7.3	2.66	221 726	696[i]	6
Detroit[h]	3 970 584	412	4.3	1.55	61 508	194	5
Cleveland	1 959 880	309	3.2	1.16	22 710	71	3
St. Louis	1 882 944	293	3.0	1.10	20 743	65	3
Pittsburgh[h]	1 846 042	256	2.7	0.96	17 769	56	3
Minneapolis-St. Paul	1 704 423	235	2.4	0.88	15 060	47	2
Houston	1 677 863	344	3.6	1.29	21 701	69	3
Baltimore[h]	1 579 781	243	2.5	0.91	14 434	45	3
Dallas	1 338 684	342	3.6	1.29	17 214	55	3
Milwaukee	1 252 457	224	2.3	0.84	10 548[j]	33	3[j]
Seattle	1 238 107	202	2.1	0.76	9 403	30	2
Miami	1 219 661	149	1.5	0.56	6 833	21	1
Cincinnati	1 110 514	182	1.9	0.68	7 600	24	2
Kansas City	1 101 787	180	1.9	0.68	7 457	23	2
New Orleans	961 728	160	1.7	0.60	5 770	18	2
Phoenix	863 357	104	1.1	0.39	3 376	12	1
Indianapolis	820 259	188	2.0	0.71	5 798	18	2

Notes: Atlanta and Washington are omitted because rail rapid transit will serve the suburbs; Buffalo, Denver, Portland, and San Diego are omitted because light rail lines are planned.

Totals for some columns are as follows: weekday passengers = 469 650, cars required = 1477, and number of possible lines = 46.

[a] Populations are from UMTA (10).

[b] The activity factor is composed of twice the number of million square feet of nonresidential building space in the CBD, plus the number of CBD employees (in thousands), plus 0.000 05 times the population.

[c] The general riding habit for regional rail service in those cities that have daily service is 8.44 (annual rides per capita) in Table 1. To avoid use of New York's unique density, Chicago and Philadelphia were used to calibrate the riding habit relative to the activity factor; Chicago is 1.03 percent and Philadelphia is 1.06 percent. The weighted average is 1.04 percent.

[d] The percentage of population riding is 3.05 in the cities in Table 1 that have daily service. To avoid New York's unique density, Chicago and Philadelphia were used to calibrate the estimates for this table by weighing the two cities in proportion to their urbanized area population. The rate is 3.32 percent, reduced for each city in proportion to their respective activity factors.

[e] The weekday passengers are 1/275.7 of the annual ridership to reflect lower weekend travel.

[f] The number of cars required is based on 318 passengers/car/weekday, including spares. If bilevel cars were used, the number of passengers per car would be 483/weekday. This is based on 104 passengers (158 for bilevel cars) in each peak, plus 110 passengers on all other midday and evening trips.

[g] The possible number of lines is based on approximately 7500 passengers/line/weekday, with higher volumes in the largest cities, with fewer lines per capita, and lower volumes in the smallest cities.

[h] Existing commuter rail service may not represent the realistic potential.

[i] In 1944, Los Angeles had 8557 population/suburban rail car. This estimate equals 12 000 population/regional rail car.

[j] My site-specific calculations in 1980 found a potential of 13 500 weekday passengers on five lines, which indicates the conservative nature of these estimates.

(PMT) during a full work shift. By way of comparison, three express bus drivers will typically produce but 6200 PMT at best; i.e.,

140 crew miles move 47 four-car train miles and 93 two-car train miles = 374 car miles at 40 PMT per car mile = 15 000; all day load factor = 38.5 percent.

Three bus drivers each make two round trips, one in each peak, carrying 47x3x2 = 282 passengers; off-peak, three round trips will average 54 passengers = 162 off peak = 444 total x 14 miles = 6216; all day load factor = 48 percent (smaller vehicles facilitate higher load factors).

Regional rail service has higher infrastructure cost than suburban bus service, but the resulting amenities (stations, weather protection, wider seats and aisles, and exclusive rights-of-way) attract more passengers and revenue to pay the cost.

A complete regional rail service requires 3.8 employees of all necessary disciplines to support each car in the fleet, whereas a bus requires only 2.25 employees for peak-hour express service with little midday, evening, and weekend service [data from meeting of New Jersey Transit Corporation on October 27, 1981, in which 2880 rail employees reported, and from other sources (4, Codes 2068, 3022, 5027, 5031, and 7006, p. 2-220; 7; 8; 9, which reports on 969 rail cars, less 160 leased out to others or in dead storage)]. Even so, the rail car will serve 4000 PMT/day (100 miles x 40 PMT/car mile), while the bus can serve only 1730 (100 miles x 17.3 PMT/bus mile).

The commuter rail employee is 37 percent more efficient or productive than the suburban bus employee in the typical case. Of course, all cases are not typical.

Employee efficiency is irrelevant, however, if service quality is not equal. Where there is no adequate railway, there can be no regional railway train. Similarly, without a well-located freeway, no express bus can compete effectively for suburban commuters.

POTENTIAL

Table 1 identifies 10 metropolitan areas with regional commuter rail service. Table 2 identifies 14 additional areas with a sufficient population density and traffic congestion problems to raise the question of the usefulness, practicality, and economy of regional rail service to reduce total travel costs, energy consumption, and air pollution while increasing mobility and central city values. In several metropolitan areas, regional rail service is being considered, but its implementation can be delayed by institutional barriers and resulting misunderstandings. It is, however, much easier to remove institutional problems than it is to change the inherent laws of physics, economics, and travel behavior.

A regional railway is less likely to be successful if it is too short. Few lines of less than 10 miles appear viable. Few commuters will ride much more than 45 min in large numbers. Express service can cover 30 miles in this time span. Lines longer than 30 miles are possible, but may be more interurban than commuter in character. New York City is an exception. Because of its huge size, many lines exceed 30 miles in length.

In many suburban metropolitan areas, densities average 1500 population/mile², but this declines with distance in typical, but not all, cases. A population of 6000/route mile is typical. A 20-mile line would serve a population of 120 000, with a riding habit (annual rides per capita) of 18 (11), which suggests a typical weekday ridership of 7000 passengers (3500 in each direction). More heavily populated areas would experience a much heavier volume of patronage, and thinly settled areas would be less. The riding habit tends to vary inversely with the square of the distance, which also impacts on actual ridership. The 7000/weekday figure is offered as a typical example to describe the order of magnitude from which to develop cost attributes and feasibility.

APPLICABLE AREAS

Given the criterion for a suburban population of 120 000/line, but with tolerance for a wide variation, there are perhaps 14 metropolitan areas in addition to the 10 areas that now have regional rail service that might well have the potential for successful implementation, as suggested in Table 2. A concentrated center city is essential to commuter rail viability, thus making success in Tampa or Tucson unlikely [data from letter from author to J.R. Gilstrap, American Public Transit Association, Washington, D.C., June 19, 1982, and from other sources (3, Chapter 2, p. 101, and Exhibits 2.14 and 2.15; 5, p. 35)].

Areas now served by regional commuter trains generate one million passengers per weekday, which is equal to approximately 3 percent of the metropolitan area population. This percentage will vary up or down in proportion to the number of lines operated, but for a metropolitan area with two million population and eight lines (the four compass points and four lines in between), 7500 average weekday riders per line may be typical--certainly similar to the abstract example developed above (5,6). (It may be significant to note that one million weekday regional rail passengers in 10 metropolitan areas is equal to all of the nation's total commercial airline travel in approximately 140 metropolitan areas.)

Regional commuter rail service should not be expected to solve all urban problems with a single installation. Each line must have its own justification in its own area. If it is justified, it should be provided regardless of its inability to solve problems outside its limited service area. Just as all motorists do not use all freeways, everyone should not be expected to use a single rail line before it is judged to be justified.

JUSTIFICATION

What is the justification for a rail line if it does not serve a majority of the population and solve most urban problems? There are several reasons why a regional rail service might be justified:

1. It may reduce the cost of travel,
2. It may reduce the transit system deficit,
3. It may relieve unacceptable highway congestion,
4. It may save energy by reducing foreign oil imports (3,5),
5. It will probably provide a safer means of travel, and
6. It may aid in the restoration of center-city values to strengthen the city's financial support.

It is not axiomatic that the provision of regional rail service will accomplish all, or any, of these advantages, but a well-designed service in a corridor of good potential should achieve most, if not all, of them.

It was determined previously that a typical service would attract 7000 average weekday riders on a radial route. To analyze the value and viability of such a regional commuter rail passenger service, a pro-forma income statement has been constructed (Table 3). At fares found optimum by existing experience (i.e., as high as possible without deterring significant ridership), it has been found that regional rail service should serve the public at a considerably reduced deficit when compared with automobile or suburban bus operation. Foreign petroleum importation could be reduced by 8 million gal/year/line if city development is affected, and by almost 700 000 gal of oil/year on the basis of travel efficiency only. (The higher saving is due to less driving, more walking, and more concentrated development with less urban sprawl.) In addition, 867 automobile trips will be eliminated from the major urban arteries in each peak hour that would not have been eliminated with suburban bus service. This traffic reduction is equivalent to adding a lane of movement to the street in each direction and it saves many millions of dollars in construction cost, as well as adds commercial activity.

SERVICE

The above calculations are heavily dependent on the service pattern established for the convenience of the potential rider. It is usually true that 95 percent of the patronage will be center-city oriented, and that more than 20 percent of these will seek to travel in a single hour in one direction: between 7:30 and 8:30 a.m. inbound and between 4:30 and 5:30 p.m. outbound.

This demand curve requires three peak trains arriving in the city at 7:45, 8:15, and 8:45 a.m. for a typical city with typical business hours. In some cities, arrival might be one-half hour earlier. The first two trains will probably require seven and eight cars, respectively, with five cars for the last arrival. In the evening, the process will be reversed at 4:45, 5:15, and 5:45 p.m.

The balance of the demand will be spread throughout the day and evening, with inbound patronage declining as time moves on. Outbound patronage will grow throughout the day until the evening peak, after which it will decline sharply. There will be minor peaks in the opposite direction, but these will not be large enough to require or justify additional resources.

Four train crews will be required to efficiently produce attractive service for 7000 average weekday riders. Three crews will be required for the morning peak. One of these will finish in 8 h, and will be replaced by the evening crew, which also works 8 h. The other two crews will work both peaks, on duty almost 10 h, with 1 h off duty at midday. Each crew will consist of an engineman, a conductor, and an assistant. Additional (extra) assistant conductors will be required for the trains in excess of four cars to ensure full revenue collection. Automated fare collection is not cost effective for this volume of travel over these distances.

To better use paid crew time and to maximize revenue, additional train service may be prudent during the off peak to fully achieve the 7000 passenger potential explained earlier. For efficiency, outbound trains would be scheduled off peak at 8:00, 9:00, and 10:00 a.m.; 12 noon; and 1:45, 2:45, 3:45, 6:45, and 9:15 p.m. These would return inbound at 9:45, 10:45, and 11:45 a.m., and 1:45, 3:30, 4:30, 5:30, 6:30, and 8:30 p.m. In total, there would be 3 round trips by each crew, or 12 in all, on weekdays.

Table 3. Pro-forma income statement of regional (commuter) rail line operation of 22 miles that serves 7000 passengers.

Item	Cost
Annual revenue	
1 929 900 passengers at $0.25	482 475
27 018 600 passenger miles at $0.095	2 566 767
Incidental revenue	45 758
Total	3 095 000
Annual operating expenses	
Maintenance of way and structures	
50 170 560 ton-miles at $0.003	150 511
15 stations	135 000
Total	285 511
Maintenance of equipment	
4 locomotives at $30 000 plus $0.67/mile	224 359
22 cars at $10 000 plus $0.40/mile	456 368
Total	680 727
Fuel: 590 920 miles at $0.50	295 460
Train and engine crews	
6 x $90 x 1.35 fringe benefits x 313 days	228 177
11 x $90 x 1.35 fringe benefits x 254 days	339 471
3 x $90 x 1.35 fringe benefits x 59 days	21 506
Total	589 154
Station agents and janitor (4)	94 000
Train supplies and expenses at $0.46/car mile	271 823
Direct supervision (3)	135 000
Promotion and advertising	36 000
Insurance and liability	50 673
General and administrative at 19.26 percent of revenue	596 252
Incentive payments, if earned	30 400
Total	3 065 000
Net annual railway operating income	30 000

Note: The following statistics can be computed from the income statement: cost per train mile = $19.68; cost per passenger mile = $0.1134; cost per car mile = $5.19; number of employees = 68; and labor-cost ratio = 64 percent.

Saturday regional rail service usually attracts 30 percent of the weekday volume. Most contracts guarantee train crews 26 days pay per month (without premium), so weekend train service does not add to crew cost. Personal business, shopping, sporting events, plus a few downtown workers account for most of the Saturday travel market. Two of the four regular crews can be assigned to work Saturday trains, which offer six round trips during the day. No evening service is likely to be justified.

Sunday and major holidays generate little more than 10 percent of average weekday travel. One crew, not worked on Saturday, can provide three Sunday noon through afternoon round trips for recreational, personal, and sporting-event travel. No early morning or evening service can be justified.

COST

Service and cost are mutually interdependent variables. Peak-hour travel physically determines the number of rail cars and locomotives needed. Peak-hour service, to achieve the potential, must provide service every half hour (or more often, if needed) to provide the necessary capacity. Off-peak service would not be justified on a fully allocated cost basis, but such costing has no basis in practical reality or in economic theory. Off-peak labor requires little if any added payroll cost. Off-peak service increases revenue and reduces unit costs of operations as well as the cost per passenger carried. Accordingly, it is cost effective to schedule sufficient service to fully use guaranteed crew time together with the minimum amount of necessary rolling stock (otherwise idle after the morning peak). Minimal evening service permits the reduction or elimination of overtime for three (in this case) midday crews; thus, it is valuable in capturing additional revenue from passengers who could not use the trains regularly because of their hours if evening service were not offered. Electric operation usually obtains off-peak power at half price, as there is no demand charge during the off peak.

Maintenance of Way and Structures

Maintenance of way and structures has been found to cost 3 mills (1982) per gross ton mile. If a single track rail line carries 10 million gross ton miles of traffic per year, the cost per track mile for maintenance will be $30 000, a generously high figure (12). Additional cost will be incurred for regional passenger stations on a site-specific basis, as identified in Table 3. Seven employees will be required in this case.

Maintenance of Equipment

Maintenance of equipment costs consist of servicing and repairing locomotives and cars plus supporting equipment. These costs include a fixed (time variable) cost and a mileage (use variable) cost. Each locomotive is estimated to cost $30 000/year, independent of use, plus $0.67/mile for each mile operated. Electric locomotives will cost 50 percent more but will produce 100 percent more output, thereby reducing the total number of locomotives where more than one per train is required.

The fixed annual cost of passenger car maintenance is estimated at $10 000, plus $0.40/car mile for each mile operated. Self-propelled coaches will cost 33 percent more if electric and 50 percent more if diesel powered, but they will avoid locomotive costs.

These cost estimates will maintain the equipment in good condition over its full life span. Fifteen employees will be required to perform the work estimated in Table 3.

Fuel

Fuel consumption in regional railway service averages 0.5 gal/car mile, including the locomotive's share. Diesel fuel was $1/gal in 1982. If electricity is used, a rate must be negotiated with a power supplier. Any price per kilowatt hour below $0.07 will be less costly than diesel fuel.

Crew Cost

Train crews usually work a 150-mile basic day, six days/week, with proportional reimbursement for additional miles or hours beyond eight (or nine if released from duty for an hour). There is no premium paid for overtime or work beyond 40 h/week. In regional railway service, it is difficult to schedule more than 150 miles/day. Actual crew costs are tabulated in Table 3. For a weekday, 17 train employees and enginemen will be required (a dozen in four crews) for a typical schedule, and five additional assistant conductors will be required in peak hours to collect tickets in the longer trains, with one additional employee for each additional pair of coaches. It may be noted that only 25 percent of the total employees necessary to provide the service are involved in on-board train operation. With bus operation, approximately 50 percent of the employees are drivers.

Station Agents and Janitors

The on-board train employees are insufficient to make change and sell tickets to all peak-hour passengers. Exact fares would discourage too much patronage and have no value on regional railway trains. Ticket sales off the train are necessary

Table 4. Alternatives analysis of annual regional rail service costs.

Item	Costs ($) Rail	Bus	Bus plus Automobile	All Automobile
Operating costs (000s)	3065	4960	5037	5115[a]
Capital amortization and interest (000s)	2750	1575	2641	3675
Total annual cost (000s)	5815	6475	7678	8790
User charges (000s)	3049	3049	5920	8790
Incidental revenues (000s)	46	15	8	0
Net public cost (000s)	2720	3411	—[b]	—[b]
Cost per passenger	3.01	3.36	3.98	4.55
Cost per passenger mile	0.215	0.240	0.284	0.325

[a] From Cupper (13). Note, these are fully allocated costs. Avoidable costs are one-half the full cost based on fuel consumption, tire wear, mileage-related servicing and repairs, added accident exposure, and accelerated depreciation.

[b] As explained in the text, a minimum highway investment of $140 million was cited as necessary for the necessary capacity to move the travel volume predicted herein. The annual cost of this investment over 40 years at 12 percent will be $14.7 million—almost twice the user charges involved. The motor fuel taxes generated for such use will approximate $177 750/year. Obviously, there can be no economic justification for highway commuting by automobile into central cities in peak hours. The highway construction cost is not included in the costs per mile cited above. Such highway construction costs equal $7.62/passenger and $0.544/passenger-mile.

for as many passengers as possible. This will require a station ticket agent in the CBD station from 7:30 a.m. to 9:30 p.m., with both shifts on duty simultaneously in the late afternoon to handle the afternoon peak. No agent is necessary on weekends. A third agent is necessary to serve passengers at the busiest suburban station and to handle monthly ticket sales by mail.

A janitor is required to serve the central station from 11:00 a.m. to 7:00 p.m., with some released time to attend to the busiest suburban station at the beginning two days of the week.

Train Supplies and Expenses

Train supplies and expenses cover the sundry costs of operating the trains, other than fuel and repairs. Seven employees, equipped with the necessary skills to make on-the-spot adjustments, will be required to furnish train supplies and to inspect the trains for safe operation. The cost of labor and supplies will be $271 823 (averaging $0.46/car mile) for the service to be provided, as shown in Table 3.

General and Administrative Expenses

Three top-level supervisors will be required to oversee the enginemen, train crews, and maintenance employees, in addition to the staff necessary to administer these functions. Accounting, claims, dispatching, payroll, promotion, and general office duties will require 15 employees and cost $500 000/year. All employee costs are based on payroll data published by the Association of American Railroads, with specific data for each classification.

Incentive

The railroad that operates a contract commuter or regional railway service must be fully reimbursed for its prudent costs, such as have been set forth in Table 3. Simple, outright full-cost reimbursement, however, is not a viable or businesslike arrangement without some incentive or penalty (for inferior performance). Accordingly, some cost for an incentive must be budgeted. A 1.5 percent additional incentive reimbursement is reasonable, based on experience, coupled with penalties for late or missed trains, cost increases above indexed levels, and losses of passenger volume in excess of peer group performance. On the likelihood that some penalty will be incurred, a 1 percent net allowance is provided in Table 3.

Total Costs of Operation

Total annual operating costs for a 22-mile, 7000 weekday passenger regional railway operation in 1982 will be approximately $3 065 000, as shown in Table 3. This will serve 1 929 900 passengers and carry them more than 27 018 600 PMT. To carry the same work load by bus (although substitute bus service is most unlikely to carry the same volume), a fleet of 49 buses would be required (at 47 seats each). These buses will average $100 000/year each in operating costs (4, Codes 1003, 3022, 3019, 5015, 5066, and 9021, p. 2-211) and will cost $0.18/passenger mile, which is 50 percent more than rail service. This difference in cost will permit operation of attractive regional rail service without the need for federal Section 5 (Urban Mass Transportation Act of 1964, as amended) operating assistance, which may be phased out. The bus service alternative is prohibitively costly.

The knowledge that other regional and commuter rail lines operate with multi-million dollar annual losses will raise the question of the accuracy of this paper, which predicts no losses at all from operations. There are at least five reasons for this difference:

1. No firemen are employed;
2. No yard crews are necessary;
3. Simple, largely unattended stations are used;
4. Rolling stock use is optimized; and
5. The proposed route is selected for its viability.

As evidence that regional rail service need not be a loss leader, for a decade the Chicago and Northwestern Railway operated its passenger service on a profitable basis, including the purchase of hundreds of new coaches. It now operates at a loss because state policy dictated subsidies to avoid fare increases that would have overcrowded highways during the past inflationary spiral.

CAPITAL INVESTMENT

Capital investment must also be considered. A fleet of four locomotives and 22 coaches, as used in this example, will require an investment of $25 million, plus servicing facilities and modest station and parking facilities equal to $2 750 000/year for capital recovery at 12 percent interest over 33 years.

The alternative capital investment for a fleet of 49 buses and a garage for them will cost $10 million--equal to $1 575 000/year. It was shown previously that bus service would cost almost $2 million more per year to operate than rail service. The added capital cost for rail is much less than the added operating cost for bus service of equivalent capacity. The same is true for automobile service. A fleet of 2917 automobiles would be required to transport the 7000 average weekday passengers likely to use train service. The annual capital cost of these automobiles would be $3 675 420, plus $2 701 860 avoidable annual cost of automobile operation and $2 412 650 for parking. There is also the automobile-associated cost of providing adequate roadway capacity, but this is so huge in a congested area that it cannot be estimated here with any accuracy. It is sufficient to point out that just one more lane of freeway for 14 miles in a radial direction in a large metropolitan area would cost

$140 million as a rough but minimal approximation.

A summary of these costs is provided in Table 4. Clearly, there appears to be a justifiable need for additional regional rail commuter service.

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Assessment of Rail Automatic Fare-Collection Equipment Performance at Two European Transit Properties

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The findings of an assessment of the performance of automatic fare-collection (AFC) equipment at two European transit properties—Tyne and Wear Transport Executive and Stuttgarter Strassenbahnen—are summarized. The properties operate in Newcastle, England, and Stuttgart, West Germany, respectively. Each has recently installed self-service ticket vendors and/or automatic gates that incorporate such new technologies as microprocessors, failure diagnostics, coin recycling, and needle printers. The analysis of the AFC equipment at each foreign property was based on a property evaluation plan (PEP) developed by Input Output Computer Services, Inc. The specific objectives of the assessment were to (a) apply the PEP to the two properties in order to assess AFC equipment performance; (b) assess any major performance differences between similar types of equipment, including equipment in use at U.S. rail transit properties; and (c) investigate innovative equipment techniques for possible use by U.S. transit properties. Analysis of performance results indicated that reliabilities for the European equipment were significantly greater than those for AFC equipment in service at Port Authority Transit Corporation, Illinois Central Gulf, Washington Metropolitan Area Transit Authority, and Metropolitan Atlanta Rapid Transit Authority. It is suggested that such state-of-the-art equipment could be used at some American transit properties. The net result could be increased maintenance productivity, enhanced unmanned station operation, and improved control of accounting data.

An assessment of automatic fare-collection (AFC) equipment performance was conducted at two European properties in accordance with procedures defined in the property evaluation plan (PEP) developed by Input Output Computer Services, Inc. (IOCS) (1). The properties examined were Tyne and Wear Transport Executive of Newcastle, England, and Stuttgarter Strassenbahnen of Stuttgart, West Germany. The assessments were conducted as part of the UMTA Rail Transit Fare Collection (RTFC) project. The UMTA RTFC project has identified a critical need for U.S. transit systems to develop improved AFC systems in order to improve operating efficiency, enhance control of receipts, and reduce labor and maintenance costs.

The two properties were selected because each has recently installed equipment that incorporates microprocessor technology, needlepoint printers, and coin recycling. Each assessment was based on data collected during an on-site survey and, where available, on transaction and failure data provided by each property.

OBJECTIVES

The objectives of the current study were threefold:

1. To apply the PEP to the two properties in order to assess AFC equipment performance;
2. To assess any major performance differences between similar types of equipment, including equipment in use at U.S. rail transit properties; and
3. To investigate innovative equipment techniques for possible use by U.S. transit properties.

DATA COLLECTION AND ANALYSIS

A data-collection plan was developed for each property in accordance with procedures described in the PEP. Each plan was designed to observe a sample of AFC equipment in service. Each plan called for data collection during peak hours for a 5-day period in July 1981.

Statistical analysis of performance measures consisted of chi-square and t-tests of proportions. The tests were used to determine whether a machine, or group of machines, exhibited a performance measure significantly different from that of another machine or group. Where significant differences did exist, failure distributions were examined in an effort to explain the differences.

Table 1. Summary of Tyne and Wear vendor reliabilities.

Period	No. of Vendors	Reliability (R)	MTF	Sample Size (transactions)
On-site data: July 13-17, 1981	19	0.999 789	4708	14 123
Property-supplied data				
April 1981	53	0.999 859	7087	503 169
May 1981	65	0.999 830	5882	647 021
May 1981[a]	53	0.999 954	6757	567 612
April-May 1981[a]	53	0.999 855	6908	1 070 781

[a] Excludes data on vendors at four new stations.

DEFINITIONS OF PERFORMANCE MEASURES

Reliability

Reliability is defined as the probability that AFC equipment or their major components or subsystems will successfully accomplish their functional task. In terms of the equipment observed at the two European properties, successful transactions were defined as follows: (a) ticket vendors--successful delivery of a ticket, and (b) automatic gates--successful admittance of a patron with a valid ticket or pass. In this report, reliability is expressed in three different ways:

1. As the probability of a successful transaction; i.e., R = (total transactions - total failures) ÷ total transactions;
2. As the mean number of transactions per failure (MTF); i.e., MTF = total transactions ÷ total failures; and
3. As the mean time between failures (MTBF); i.e., MTBF = total in-service time ÷ total failures.

For the computation of reliability measures, two sets of data were used. The first set was data that IOCS observers collected during on-site observations, where transaction, failure, and operating-time data were collected for each type of machine. The second set of data was that maintained by the property. For example, transaction data on equipment were provided that indicated tickets sold or patrons admitted or allowed to exit. Failure data were either in the form of permanent maintenance records for each machine or failure reports filed by technicians.

It is important to note that reliability measures based on property-maintained data are most often higher than reliabilities based on data collected by on-site observers. This situation occurs because maintenance records and failure reports do not record all jams and do not indicate how many times a machine failed to complete its mission before a failure was detected and corrected.

Availability

Availability is defined as the probability that AFC equipment will be operating satisfactorily at any point in time. Availability is calculated by dividing the total in-service time by the total operating time and converting the result into a percentage. Total operating time is comprised of (a) total in-service time (operating and available for service), and (b) total downtime (i.e., combined duration of all failures, including active repair time and response and logistic time). An example of logistic time is time spent going for parts. Availability (A) is expressed as follows: A = (total operating time - total downtime) ÷ total operating time.

Maintainability

Maintainability is defined as the time required to repair failures, and it is usually expressed as average downtime (ADT) and mean time to repair (MTTR). ADT is the more widely used measure and indicates the average time that AFC equipment will be out of service per failure. It is calculated as follows: ADT = total downtime ÷ total failures.

MTTR statistics are developed for hard failures that require action by a maintenance technician. Hard failures are defined in the PEP as failures that require an active repair time greater than 20 min or require component replacement. MTTR is based on the total downtime for all hard failures and the total number of hard failures. It is expressed as follows: MTTR = total downtime (hard failures only) ÷ total hard failures.

PROPERTY DESCRIPTIONS AND RESULTS

Tyne and Wear Metro

The Tyne and Wear Metro operates an integrated bus and rapid rail system that serves approximately 1.2 million people in Newcastle, England, and its surrounding communities. The Metro rail system opened in summer 1980 and will encompass 34 miles and have 41 stations when completed in 1983. As of July 1981, 14 miles and 18 stations were open, serving a weekly ridership of 180 000. Fares are based on the number of zones traveled.

The AFC system consists of 68 self-service vendors, 30 booking-office machines, and 89 passenger entry gates, of which 29 are fully accessible gates designed for handicapped passengers. The vendors and booking-office machines were manufactured by Crouzet of France. The cabinets and mechanical barriers of the gates were built by Cubic-Tiltman Langley, and the microprocessor-controlled magnetic ticket readers were manufactured by Crouzet.

The Tyne and Wear vendor incorporates a reprogrammable microprocessor, failure diagnostics, needlepoint printer, and coin-recycling subsystem. The machine accepts only coins (five types), and dispenses single magnetically encoded one-trip paper tickets of the Edmondson size (1.1875x2.625 in). The automatic gates can accept the tickets inserted in any of four possible orientations.

Equipment Performance: On-Site Data

Table 1 summarizes the reliabilities computed for Tyne and Wear vendors. The reliability of a sample of 19 vendors was measured at 4708 MTF based on more than 14 000 tickets vended. MTBF was measured at 71.7 h. The reliability of a sample of 16 gates was measured at 10 299 MTF based on more than 20 000 entries; the MTBF was 91.1 h.

Availability measures were also generated based on the on-site data. Vendor availability was 99.6 percent based on more than 215 h of machine operation. For the gates, availability was 99.8 percent based on more than 182 machine-h. ADT for both the gates and vendors was 13 min based on a relatively small number of failures. MTTR figures were not generated because no hard failures occurred.

Vendor failures were two ticket jams and a coin jam in the recycling subsystem. Only two gate failures occurred. One resulted from dirt and ticket dust that accumulated around a sensor in the ticket reader. The other was a ticket jam in the reader.

Table 2. Summary of SSB vendor reliabilities.

Period	No. of Vendors	Reliability (R)	MTF	Sample Size (transactions)	Comment
On-site data: July 27-31, 1981	10	0.999 451	1 821	5 464	
Property-supplied data					
1980	489	0.999 929	14 042	15 544 955	Technical failures only
January-June 1981	485	0.999 921	12 728	7 344 284	Technical failures only
January-June 1981	485	0.999 698	3 311	7 344 284	All failures
January-June 1981	485	0.999 856	6 948	7 344 284	Technical plus other selected failures (e.g., plugs and cables)

Equipment Performance: Property-Supplied Data

Reliability was also measured for vendors and their magnetic ticket issuer and reader subsystem based on property data from April and May, 1981. The system total reliability in April was 7087 MTF, whereas for May the MTF measure was 5882. The May figure included the performance of vendors at four new stations. When these machines were excluded, the May vendor reliability was 6757 MTF, a 5 percent decline that was not statistically significant. When the April and May figures were combined and the vendors at the new stations not considered, the reliability was 6908 MTF based on more than one million tickets sold.

For the magnetic ticket issuer and reader subsystem, the April reliability was 14 799 MTF for the 53 vendors in the Metro system. For the same machines, the May reliability was 13 844 MTF, a 7 percent decline that was not statistically significant. For the 53 vendors, the 2-month MTF measure for this subsystem was 14 277.

The failure data provided by the property were examined and distributions were generated. The distribution of 155 vendor failures for April and May by major subsystem affected was as follows: magnetic ticket issuer and reader, 48 percent; coin-recycling subsystem, 25 percent; coin selector, 10 percent; and logic, 3 percent. (The remaining 14 percent affected miscellaneous components.) Approximately 80 percent of the coin-acceptor failures were jams.

Stuttgarter Strassenbahnen

Stuttgarter Strassenbahnen (SSB) operates an extensive trolley and bus system that serves approximately two million people in Stuttgart, West Germany, and its surrounding communities. The SSB system comprises 10 trolley lines with 400 trolleys and 60 bus lines with 300 buses. Ridership on the SSB is approximately 400 000/workday. Fares are based on the number of zones traveled. A barrier-free system is used, whereby passengers are responsible for their own ticketing, and access to and from the system is not controlled except by random inspection.

The AFC system consists of approximately 490 self-service vendors and ticket cancellers. The vendors are located at every trolley stop and at high-passenger-volume bus stops. The vendors were manufactured by Autelca of Switzerland. They accept coins only (five types) and dispense single one-trip and multitrip paper tickets that are not magnetically encoded. Similar to the Tyne and Wear vendors, the machines incorporate a reprogrammable microprocessor, failure diagnostics, needlepoint printer, and coin recycling. The cancellers are located on each vehicle for use with the multitrip tickets.

Equipment Performance: On-Site Data

Table 2 summarizes the reliabilities computed for SSB vendors. The reliability of a sample of 10 vendors was measured at 1821 based on more than 5000 tickets vended. MTBF was measured at 45.3 h. Availability of the sampled equipment was almost 100 percent based on 136 machine-h of operation.

Equipment Performance: Property-Supplied Data

Extensive data were provided by the property, which included a summary of 18 months of transaction and failure data for the entire system. For 1980, failure data were available for technical failures only. For the first six months of 1981, data on all types of failures (e.g., vandalism and administrative failures) were available. (An example of an administrative failure is faulty ticket stock used in the machine.)

Reliability for the SSB system for 1980, based only on technical failures, was 14 042 MTF. Tickets vended exceeded 15 million. In the first six months of 1981, the systemwide MTF measure, based on technical failures, was 12 728. For the same period in 1980, the MTF measure was 13 080. The 10 percent decline was not found to be statistically significant.

Other systemwide reliability measures for the first six months of 1981 were generated based on various categories of failures. The reliability, based on all failures (including vandal-related), was 3311 MTF. The systemwide reliability of the needlepoint printers, based only on technical failures, was 32 497 MTF.

A distribution of technical failures for the first six months of 1981 was generated by the subsystem or component affected. The hierarchy of the 577 technical failures by major subsystem was as follows: needlepoint printer, 39 percent; coin-guiding plate, 16 percent; coin-recycling discs, 14 percent; coin acceptor, 9 percent; and logic, 6 percent. (The coin-guiding plate directs coins into the appropriate recycling disc.)

COMPARISON WITH EQUIPMENT USED AT U.S. TRANSIT PROPERTIES

The performance of the AFC equipment at Tyne and Wear and SSB were statistically compared with the performance of similar equipment in service at American transit properties. The American properties used in the comparison included Port Authority Transit Corporation (PATCO), Illinois Central Gulf (ICG), Washington Metropolitan Area Transit Authority (WMATA), and Metropolitan Atlanta Rapid Transit Authority (MARTA). Comparisons were made separately for figures generated from on-site and property data. Where significant differences in

Table 3. Comparison of vendor reliability based on on-site data.

Property	No. of Vendors	Reliability (R)	MTF	Sample Size (transactions)	Failures
Tyne and Wear	19	0.999 789	4708	14 123	3
SSB	10	0.999 451	1821	5 464	3
ICG	9	0.996 613	295	5 019	17
WMATA (pre-retrofit)	40	0.993 759	160	153 983	961
WMATA (retrofit A)	14	0.994 282	175	20 638	118
WMATA (retrofit B)	6	0.997 630	422	20 673	49

Table 4. Comparison of reliability of automatic gates based on on-site data.

Property	No. of Gates	Reliability (R)	MTF	Sample Size (transactions)	Failures
Tyne and Wear	16	0.999 903	10 299	20 597	2
ICG	28	0.999 781	4 570	86 842	19
WMATA (pre-retrofit	24	0.998 007	502	191 696	382
WMATA (retrofit A)	18	0.998 592	712	134 268	189
WMATA (retrofit B)	7	0.999 551	2 220	153 600	69
MARTA	26	0.999 425	1 740	106 122	61

performance were found, failure distributions were examined in an effort to explain the differences. Failures that were related to bill acceptors were not included in the assessment because the European machines do not incorporate the devices.

For the vendors, based on the on-site data, both the Tyne and Wear and SSB machines had MTF measures significantly greater than those for ICG and WMATA at the 95 percent confidence level. (Note that the American vendors dispense magnetically encoded farecards of the credit-card size.) As can be seen in Table 3, the WMATA measures included the reliabilities measured for two retrofit programs. An examination of performance differences based on failure data was not possible due to the low number of failures that occurred in the European machines.

The comparison based on property-supplied data had similar results. Both Tyne and Wear and SSB vendors had MTFs significantly greater than those for PATCO and ICG at the 95 percent confidence level, as seen from the table below:

Property	Reliability (R)	MTF	Sample Size (transactions)	Failures
Tyne and Wear	0.999 855	6908	1 070 781	155
SSB	0.999 761	4178	7 344 284	1758
PATCO	0.996 846	317	97 960	309
ICG	0.992 074	126	10 976	87

An examination of failures indicated that distributions were similar.

For automatic gates, the comparison was based only on the on-site data because property data for the Tyne and Wear gates were not available. The reliability for the Tyne and Wear sample was significantly greater than that for both the MARTA and WMATA gates, both preretrofit and postretrofit (Table 4). The performance of the European gates was also greater than that of the ICG gates. However, the difference was not found to be statistically significant.

Maintenance

This section presents summary descriptions of the maintenance organizations of the two European properties and two American properties, PATCO and ICG. In addition, the impact of maintenance on the performance differences between the European and American equipment is discussed.

As part of the original contract with Crouzet, Tyne and Wear was provided a one-year equipment warranty. The AFC maintenance organization comprises six electronic technicians and two engineers (i.e., senior technicians and a supervisor). Under a program initiated by Tyne and Wear, three of the technicians are Metro employees who are being trained to repair equipment after the warranty period is over.

Maintenance is divided into two levels. The first is on-site correction and routine preventive maintenance. The latter is carried out on gates and vendors about every six weeks in accordance with an extensive checklist of items. The second level consists of repairs and overhauls in the workshop.

When a gate or vendor goes out of service, a control center is automatically notified via a computerized remote-control indicator (RCI) system. The message sent to the center indicates whether the out-of-service condition is due to a technical failure. If so, a supervisor at the center informs a maintenance technician in the field by two-way radio.

The SSB AFC maintenance organization comprises 25 technical and maintenance support personnel located at a central workshop. During the day, there is a team of two technicians in the field who are in radio contact with the central facility. The field technicians make necessary minor adjustments (e.g., clearing paper jams in the printer or removing bent coins). In addition, for both preventive maintenance and major repair, the technicians replace components and subsystems and bring them back to the central workshop where more highly skilled personnel attend to the equipment. Several of the major subsystems, such as the printer, coin acceptor, and coin recycler, are replaced and preventively maintained about once a year. However, machines that experience extensive use usually have the printer replaced every six months.

The PATCO AFC maintenance organization consists of 10 people: 1 foreman, 8 electronic technicians, and 1 repairman. On weekdays during the daytime hours (including both morning and evening peak periods), there are two technicians in the field who respond to calls for repair from an operator in a monitoring center. One technician covers the Pennsylvania side and the other the New Jersey side of the system. (PATCO has 75 gates and 61 vendors in 13 stations. The vendors were placed into service in 1969 and the gates in 1975.)

The operator receives patron complaints and information concerning AFC equipment problems and contacts the appropriate technician. The technicians do repair work only. When finished with a job, they call the operator to let it be known that the repair has been done and inquire about another job. In some cases, these technicians will find and repair unreported failures.

In addition to the field technicians, the foreman, two electronic technicians, and the repairman work at a central shop facility. One of the technicians and the repairman do preventive maintenance and overhauls. The second technician does component repair, primarily on electronics and coin acceptors. At PATCO, vendors are not preventively main-

Table 5. Comparison of European and American AFC equipment performance and maintenance work loads.

Property	Vendors	Vendor MTF[a]	No. of Gates	Gate MTF[b]	No. of AFC Maintenance Personnel	AFC Equipment per Worker
Tyne and Wear	65	6908	89	10 299	9	17.1
SSB	485	4178	NA	NA	25	19.4
PATCO	61	317	75	5 907	10	13.6
ICG	112	126	169	4 570	19	14.8

Note: NA = not applicable.

[a] MTFs based on property data. [b] MTFs based on on-site data (except PATCO).

tained but are attended to on a repair basis. Gates, on the other hand, are preventively maintained on a fixed schedule by component.

The ICG AFC maintenance organization consists of 29 persons, 2 of whom are supervisors. This number includes a group of six field electronic technicians responsible for the upkeep of the passenger assistance line (PAL) equipment. (PAL is a central monitoring facility that provides patron assistance by closed-circuit television and a public-address system.) Another group of four electronic technicians work at the central workshop and do equipment rebuilding, redesign, and modification under a research and development program.

The remaining personnel do repair and preventive maintenance of vendors and gates and are assigned into one of four coverage areas, each with its own small shop. (ICG has 169 farecard-accepting gates and 112 vendors in 49 stations. The vendors and gates were installed between 1973 and 1976.)

On weekdays during daytime hours (including both morning and evening peak periods), there are either one or two electronic technicians covering each area. These workers are contacted by PAL operators who inform them of equipment problems. If not working on a repair, the technicians are preventively maintaining the equipment. (Gates and vendors are preventively maintained about once a week.) In rare instances where a bench is required, the technicians will bring a part back to a shop for repair.

At the central maintenance facility there are three electronic technicians assigned to do simple electrical and mechanical repairs. Sometimes these workers are dispatched to the field to handle additional work load.

Maintenance and Performance

The impact of maintenance on the performance differences between the European and American equipment was considered. With respect to reliability, this impact is difficult to quantitatively assess because of several important factors, such as the age and technology of the equipment in service, as well as maintenance policy, organization, and technician skill levels and work loads.

Nevertheless, a rough estimate of level of effort can be generated based on measures of equipment per maintenance personnel. These have been generated for Tyne and Wear, SSB, PATCO, and ICG and are given in Table 5 with corresponding reliability measures. (Note that the vendor MTFs are based on property data. The gate MTFs, with the exception of the PATCO figure, are based on on-site data.)

As can be seen in Table 5, SSB and Tyne and Wear have higher equipment per maintenance personnel ratios; i.e., in general, technicians and repairmen cover more machines, yet the reliabilities of the equipment were higher than both PATCO and ICG (significantly higher in the case of the vendors but not significantly higher for the gates). However, it is not possible, based on such limited data and the cautions presented above, to infer with any statistical confidence the predominant reason or reasons for this anomalous situation. In other words, it is just as likely that the significantly greater performance of the European equipment is due to equipment characteristics (i.e., state-of-the-art technology) than to maintenance policy, organization, or technician skill or level of effort. Common sense suggests that a mix of the factors is responsible, but isolating any of these is not possible based on limited data.

APPLICATION TO U.S. PROPERTIES

The state-of-the-art technology found in the Tyne and Wear and SSB equipment could enhance unmanned station operation and improve failure identification, repair productivity, and control of accounting data. For example, with a coin-recycling system, the vendors do not have to be regularly filled with coins as do the ICG vendors. Coupled with a high-capacity vault subsystem, this allows for longer periods of service without opening the machine.

The microprocessor technology provides capability in a number of areas: reprogramming of fares, failure diagnostics, and control of accounting data. Reprogramming of fares can be done quickly with the insertion of a new program in the logic. The program can be placed in the machine and set to trigger fare changes automatically on a given date.

The failure diagnostic capability provides a quick indication of the type of failure. This could enhance the productivity of equipment repairs because technicians would not have to spend much time isolating the problem. In addition, failure diagnostics can improve the recording of failures by providing technicians with clearly assignable failure categories.

For the accounting function, the machines can maintain an extensive array of accounting data for long periods or be programmed to deliver data to a central computer. If the latter capability is used, machine openings can be limited to vault pickups, ticket stock refills, and necessary maintenance actions.

For the older American AFC systems, such as ICG and PATCO, the coin-recycling and microprocessor technology could enhance system operation and efficiency. However, use of vendors such as those in service at Tyne and Wear would require the use of gates that accept the Edmondson-sized tickets.

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Effect of Crowding on Light Rail Passenger Boarding Times

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Passenger congestion may have important effects on passenger level of service and station stop or dwell times. In order to examine this concept, research on boarding and alighting times of passengers on light rail vehicles was conducted by sampling rush-hour operations on the Presidents' Conference Committee vehicles of the Massachusetts Bay Transportation Authority's (MBTA) Green Line, a high-volume, light rail subway-surface line. The boarding process is emphasized here, but similar treatment has been undertaken for alighting. Linear regression relations were calibrated between the number of passengers boarding per unit time and concurrent passenger counts (or densities) on board the vehicle and on the platform. These alternatively formulated models reflect the trends in the raw data that the boarding rates decline markedly under increasing congestion, especially as the space per standee falls below the often used nominal standee space level of 2.7 ft^2/standee and approaches crush-capacity density of 1.5 ft^2/standee. On the other hand, at freer circulation levels, these models provide predictions quite similar to predictions from constant-service-time models frequently formulated in earlier research. The modeling approach and subsequent results can be absorbed in future research and operational endeavors for MBTA, for other operating authorities, and for vehicle manufacturers in (a) quantifying the effects of passenger congestion on travel time and reliability, (b) permitting more refined simulation models of travel time, (c) providing a practical approach toward evaluation of realistic vehicle capacity through knowledge of circulation difficulties manifested in low boarding rates, (d) supporting short-term and low-cost operational measures to alleviate frequent problems of rush-hour service, and (e) planning new system or rolling stock requirements.

This paper is based on earlier research (1) and consists of an abridgment of coverage of that work. In particular, the emphasis given here is on the boarding process where only one of the vehicle doors is in use to process passengers who are queued to enter or exit the vehicle. The original work also covered the alighting process, as well as further treatment of multiple doors in processing passengers.

Congestion may have an important impact on station stop or dwell times. As passengers board, they must circulate on board to their respective resting positions to sit or stand. Passenger congestion may prevent passengers from circulating within the vehicle as freely as they would desire without interactions. One can term this relative freedom, or ability to circulate, as the circulation potential. Several authors (2-4) have found a reduction in flow rate, or the number passing through the doors in unit time, when standees are present; however, fluctuations in flow rate parametrically related to varying passenger densities (passengers per unit area of floor space) have not been established. Moreover, only limited attention has been given to studies of light or heavy rail systems or of bus transit corridors where high passenger densities are the rule rather than the exception. The focus of this study extends models of passenger service time--the dwell-time components related to boarding and alighting--to include high-density situations; subsequently, passenger service times in both high- and low-density situations are compared.

Indeed, actual circulation patterns on board the vehicle are difficult to quantify. Kraft (3), in his development of passenger vehicle interface (PVI), hypothesized that the manifestations of passenger-passenger and passenger-vehicle interface might be reflected in the rate at which groups of passengers enter or exit the vehicle. Possibly, low-circulation potential might be reflected in slower passenger service times--quantities that are relatively more amenable to measurement than circulation patterns themselves.

Experimental designs must be carefully chosen if results and conclusions are to be generic in nature. For example, boarding observations of vehicles with fare payment, which are typical of most of the previous studies, involve access to the vehicle, the fare payment itself, and access to the vehicle interior. However, time-consuming fare payments may confound any congestion effect due to access times.

In order to fill this research gap, and at the same time select an appropriate sampling frame, the Massachusetts Bay Transportation Authority's (MBTA) Green Line, a network of high-volume light rail routes that merge in the Central Subway, was selected as the site at which to investigate possible impacts of passenger-vehicle interaction on passenger service times under congested conditions. Several pertinent reasons accompanied the choice of the Green Line:

1. Long dwell times that constitute a high percentage of travel time (2);
2. High daily rush-hour passenger volumes (2);
3. Prepaid fares that eliminate the need to stop and pay on board;
4. MBTA's President's Conference Committee (PCC) fleet (the Boeing Standard Light Rail Vehicle fleet was not yet in operation at the time this study was initiated), which is an historical and well-used vehicle that is still in use there and elsewhere; and
5. Unique platform berth variations for comparative analysis when one, two, or three doors per vehicle are in use at a given station.

By expanding on Kraft's PVI dwell-time studies concept, this focused sampling frame, with several variables controlled, was used in producing a generic modeling approach for better understanding the effects of passenger congestion. Two proxy variables, observable or estimable from the platform, were selected to reflect circulation potential and level of service: passenger flow rates at the vehicle door, and the estimated passenger load volumes on board the vehicle, respectively. The latter are inversely proportional to standee densities.

After the data-collection phase of the study was completed, two modeling approaches were examined (each calibrated through linear regression) to predict the passenger service time on light rail vehicles: (a) the total dwell time required to board and/or alight all waiting passengers (the traditional model, which assumes constant boarding rates for each additional, or marginal, passenger), and (b) the time required for each passenger to board and/or alight given concurrent environmental conditions (the alternative set of models where, for example, high and low congestion levels are taken into account). The second approach is an extension of the first approach into more widely ranging passenger processing situations than previously undertaken. Even though derived from an alternative point of view, dwell-time predictions will be similar when passenger density is low. The conceptual framework developed here with the alternate models may prove potentially useful as an aid to researchers and transit operators in evaluating impacts of high-density patronage and interacting system components on level of service.

BACKGROUND

Research studies from the available literature were found to deal with two quantities relevant to passenger congestion and dwell-time delays: passenger density and passenger service times. These quantities relate to both pedestrian and transit network levels of service. However, no definitive studies were found that analyze passenger congestion effects when congestion is high.

Level-of-Service Concept

The transit system level-of-service (LOS) concept includes three criteria relevant here: travel time, reliability, and passenger density. Although MBTA, for example, uses a standard standee space allowance of 1.5 ft^2 in assessing vehicle capacity, Alter (5, p. 38) maintains that even 2.1 ft^2/standee should be avoided in actual operations due to the high level of physical interactions between passengers on board at these high densities.

Going beyond these authors, Fruin (6) concentrated on pedestrian LOS. A number of his approaches and findings are of great use in planning and evaluating transit system components such as passageways, stairways, bus and light rail vehicle stairwells, queuing at vehicle berths, and on board standing conditions. Furthermore, his descriptions of movement potential at various densities provide an alternate check on evaluating dwell-time model results under various operating conditions. By using Fruin's terminology, the type of queues found on the subway platform are "bulk" queues, which are unordered and without queue discipline, whereas "lineal ordered" queues are first-in, first-out type queues typically found at ticket counters. Fruin segmented pedestrian standee spacing into six zones (6, pp. 85-87), depending on the degree of bodily contact and possible circulation. The zone names are free circulation, restricted circulation, personal comfort, no-touch, touch, and body ellipse; the latter corresponds to an area of less than 2 ft^2, with ensuing physical and psychological discomfort. The two measures used most often to rate vehicle capacity--design capacity and crush capacity--fall into the touch and body ellipse zones, respectively. Design capacity has been characterized as a standing load with a minimum freedom of movement, typically 2.7 ft^2/standee (7), when specified. Crush capacity has been defined as the maximum passenger capacity of a vehicle such that a passenger can still board without causing serious discomfort to other passengers; 1.5 ft^2/standee is MBTA's standard.

Passenger Service-Time Studies

Although there have been numerous efforts in the United States and Great Britain (3,4,8) to study the boarding and alighting process characteristics of fare-paying passengers on buses, most of the limited studies available that examine light rail (3,8) capture these latter modes under operations more typical of the bus mode (i.e., fare paying on board, moderate patronage levels) than of high-volume rail lines; hence, opportunities to transfer results to the high-volume Green Line may be limited. Simple regression models, with average service time per passenger to board and alight, were generally calibrated. Among the significant factors found were fare systems, vehicle access, personal effects carried, presence or absence of standees, and vehicle type.

Kraft (3) developed the PVI, which is measured in terms of passenger service time, to denote the interaction between passengers and transit system elements while passengers board or alight. The presence and impact of PVI was tested under several service conditions, such as whether passengers were boarding only, alighting only, or both simultaneously; varying door geometries; the type of passenger; and varying fare-collection systems.

Kraft, in his Newark PCC dwell-time studies, notes that passenger service times may not have been affected if only a few standees were present and they did not hinder movement. In searching for a generalized approach, Kraft (3, p. 163) quotes Radelat (4): "No definite effect can be detected from the presence of standees....It could be possible that the retarding effect of the standees is stronger as their number increases, but this possibility could not be investigated for lack of data." Kraft recommends data collection and models to "relate the density of standees with changes in the passenger service requirements" (3, p. 148). The design selected for this Green Line study has attempted to fulfill this need to extend the research sampling frame into situations with more limited circulation potential.

DATA COLLECTION

PCC vehicles at several high-volume MBTA Green Line stations were surveyed during January 1975 under normal, but not adverse, winter weather. Several important characteristics of the data-collection process are noted here. Most of the detailed passenger transaction observations were made at the Park Street and Government Center stations, the two heaviest volume stations. A significant number of observations were of vehicles berthed with only the left center door open for passenger processing. Time intervals of 10 seconds (s) for recording passenger transactions were chosen as a practical compromise between human recording accuracy and the aforementioned need for collecting data on intervals short enough to discover dynamic effects as congestion builds. In order to capture information on arrival and departure loads, scale values of 1 to 5 were used as indices to represent the range of 0 to 142 passengers possible on the newer PCC vehicles.

MODEL CALIBRATION

Model Approaches

The passenger processing information permitted the establishment of two data set formats for use in the analysis: (a) disaggregated, 10-s passenger counts for each individual door of the vehicle, and (b) aggregation of the above 10-s counts into total time and total passenger counts for each door monitored. The analysis here concentrates on vehicles with a single left rear door operating at the station berth, with some mention of vehicles with two right-side doors open.

One of the objectives of this research was to test hypotheses relating to retarding effects of passenger congestion on dwell time. The aggregate or traditional approaches have assumed, or implied, that boarding and alighting rates are constant throughout the dwell-time period. In order to test the alternative retarding-effect hypothesis, the disaggregated data were used to observe dynamically changing conditions during the dwell-time period. The disaggregate models, as formulated, can accommodate effects such as bulk queues with pressure on those at the head of the queue, changing circulation potential as passenger density increases, and passengers turned away when doors of a fully loaded train close.

Two approaches were pursued to calibrate regression models of passenger processing: (a) the traditional linear regression model that uses aggregate boarding and alighting counts to predict dwell-time components, and (b) alternative formulations calibrated on the disaggregated data to explain variations in observed rates due to other observable variables that undergo changes during the dwell-time period. Simple algorithms based on these models can be developed to predict dwell time.

Aggregate Model Calibrations

Calibration of the traditional dwell-time modeling approach used aggregate counts of passengers boarding or alighting at each door. These simple models are limited by the implicit assumption that both free circulation passenger processing and passenger processing under congestion can be modeled by using a single constant rate of passenger flow. Scattergram plots (not shown) suggested that the calibrated straight-line curves underestimate passenger processing times at higher boarding counts where congestion is necessarily on the increase, despite R^2 statistics in the range of 0.8-0.9 and tight fits at lower boarding counts. Consequently, there may be other important variables not being considered in these formulations to explain the possible model bias.

Disaggregate Data Subset Handling

The raw data, which consist of the original 10-s observations, were classified according to subclasses such as vehicle vintage, door observed, whether standing room only was present, and number of doors available at the particular platform observed. The significant variables that were used in the disaggregate models are given below to explain the variation in the dependent variable RATE:

1. RATE: RATE(N) is the passenger processing rate, or observed number of passengers being processed during the Nth 10-s interval.
2. PASS: PASS(N) is the current estimated on board passenger count at the end of N time intervals. Subsequent values of PASS depend on net passenger count changes.
3. REM: REM(N) represents the number of passengers still remaining on the platform in front of each operating door at the end of N time intervals waiting to board. REM measures a hypothetical affect of the pressure exerted on those in front of the queue about to board. Such impact could be both physical or psychological in nature.
4. SEQ: SEQ represents the sequence number (e.g., N) of the observed passenger boarding interval and relates any effects that are dynamic in a temporal sense.
5. FRONT: FRONT is a dummy variable that represents differences between the boarding rates at the right front (FRONT = 1) and right center (FRONT = 0) doors of the PCC vehicles. Adams (2) notes that circulation patterns at the front, center, and rear of the cars are different.
6. REMSQ: REMSQ = REM * REM (quadratic REM term).
7. PASSREM: PASSREM = PASS * REM (interactive term).

Disaggregate Model Calibrations

For each of the striated data subsets, the variables on board passenger load (PASS), passengers still waiting on platform (REM), and the 10-s interval sequence number (SEQ) were individually examined for univariate relations with the boarding rate (RATE). RATE, PASS, and REM are variables that continuously change during the dwell-time period and cannot be incorporated in the aggregate model. Subsequently, multivariate relations that use the variables listed above (items 1-7) were also tested. For each data subset, the following generalized hypothesis was tested by using the Statistical Package for the Social Sciences (SPSS) REGRESSION procedure:

> H_0: The variation in the boarding rate (RATE) is not explained by any one of the six variables, either taken individually or in groups. Moreover, there is no statistically significant improvement offered by any linear combination of these variables over the model where RATE remains constant.

All models shown in Table 1 are significant, as are all variables in the multivariate models. Therefore, H_0 can be rejected for each of the data subsets examined, inasmuch as at least one linear combination of variables, and often several, were significant within each data set. The general trends of the decreasing marginal boarding rate--the rate for each successive boarding passenger that decreases as passenger density increases--appear both graphically strong and statistically strong, as evidenced by the sample scattergram in Figure 1 and the F statistics in Table 1. [Note, for Figure 1, the plot, which is based on left-center-door observations of the pre-1951 car, shows the general trend of monotonically decreasing boarding rates (RATE) as the on board passenger load volume (PASS) increases and approaches crush capacity. The calibrated regression line for these points is RATE = 13.51 - 0.0883 * PASS.]

The univariate regressions of Table 1 of the form RATE = $b_0 + b_i * x_i$ were further examined. As may be seen from Table 2, several consistent patterns in the coefficient values were found. These are briefly described below:

1. The univariate relations between RATE and PASS for heavy-load boarding are reasonably uniform within each of the single door data subsets.
2. The generally consistent and positive values of b_{REM} suggest a pressure-induced increase in boarding rates when the bulk queues are larger.
3. Light-load boarding situations appear only to be explained by linear and quadratic functions of REM, except in the case of the pre-1951 car (left center door) light-load situation where PASS, too, was significant. This justifies testing REM for significance in other multivariate heavy-load hypotheses.

Table 1. Regression calibrations: variables and model statistics.

Data Set			Sample Size	Variables Included in Equation	R^2	F
Car	Door[a]	Load[b]				
Pre-1951	LC	Light	76	REM	0.554	91.9
				PASS	0.241	23.5
				REM, REMSQ	0.648	67.2
1951 era	LC	Light	17	REM	0.677	31.4
Pre-1951	LC	Heavy	329	SEQ	0.509	338.5
				PASS	0.429	245.8
				REM	0.239	102.4
				PASS, REM, SEQ, PASSREM	0.574	109.3
1951 era	LC	Heavy	125	SEQ	0.412	86.2
				REM	0.336	62.3
				PASS	0.294	51.1
				SEQ, REM, REMSQ, PASS	0.625	50.0
Pre-1951	RC	Heavy	111	PASS	0.466	95.1
				REM	0.391	70.0
Pre-1951	RF	Heavy	100	PASS	0.430	73.8
				REM	0.257	33.9
Pre-1951	RC and RF	Heavy	211	PASS, REM, REMSQ, FRONT	0.625	86.0

Note: The variable sets included here cover both significant univariate equations and significant multivariate equations with at most four variables and the highest R^2 statistics at that depth. The data subsets shown here focus on those vehicles berthed such that only the left door was open for passenger processing. As a guide to the significance testing, $F^{1,60}_{0.05} = 4.0$.

[a] LC = left center, RC = right center, and RF = right front.

[b] Heavy = standees among the newly boarding passengers and light = all newly boarding passengers guaranteed seats.

Figure 1. Scattergram plot for boarding rate versus PASS, the on board passenger load.

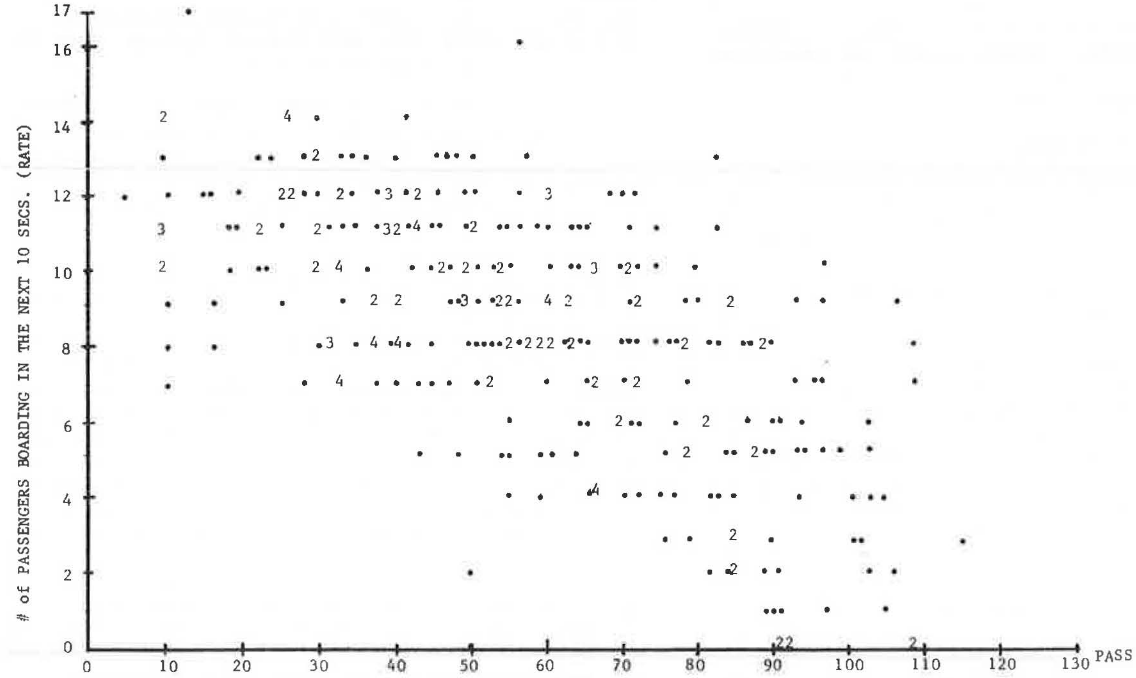


Table 2. Univariate regression coefficients for disaggregate model calibrations.

Data Subset			Independent Variable i	b_0	b_i	Standard Error
Car	Door[a]	Load[b]				
Pre-1951	LC	Heavy	SEQ	12.15	−0.997	0.054 0
1951 era	LC	Heavy	SEQ	11.81	−1.192	0.128 0
Pre-1951	LC	Light	PASS	11.93	−0.186	0.038 4
Pre-1951	LC	Heavy	PASS	13.51	−0.0883	0.005 63
1951 era	LC	Heavy	PASS	12.25	−0.0608	0.008 50
Pre-1951	RC	Heavy	PASS	12.09	−0.0811	0.008 32
Pre-1951	RF	Heavy	PASS	9.85	−0.0673	0.007 83
Pre-1951	LC	Light	REM	4.40	0.323	0.033 7
1951 era	LC	Light	REM	5.25	0.236	0.042 1
Pre-1951	LC	Heavy	REM	3.90	0.154	0.015 2
1951 era	LC	Heavy	REM	5.04	0.112	0.015 1
Pre-1951	RC	Heavy	REM	4.77	0.148	0.017 7
Pre-1951	RF	Heavy	REM	3.86	0.128	0.022 0

Note: These models are of the form $RATE = b_0 + b_i * x_i$. The standard errors of the independent variable coefficients are also shown. Only RATE models for boarding are shown in this table.

[a] LC = left center, RC = right center, and RF = right front.

[b] Heavy = standees among the newly boarding passengers, and light = all newly boarding passengers guaranteed seats.

4. Compared with the pre-1951 vehicles, the more spacious 1951-era vehicles exhibited less of a drop-off in boarding rates with equal numbers of standees.
5. Although the coefficients of the examined multivariate regressions are not shown here, the signs of b_{PASS}, b_{REM}, and b_{SEQ}, as would be expected from the univariate equations, exhibit reasonable and desirable coefficient "stability" among the regressions.
6. In addition, significant relations for alighting and multidoor boarding were also found and are described in greater detail in Fritz (1).

PREDICTIONS BY USING PASSENGER FLOW-RATE MODELS

Methods for Prediction

The calibrations of the alternative models suggest that the selected variables (PASS, REM, SEQ, FRONT, REMSQ, and PASSREM) explain significant amounts of the variation in RATE. The univariate equations are much simpler than the multivariate equations in both concept and ease of generalizing relations in single equation solutions. Therefore, univariate equations would be useful to the planner who would desire to use easily understood relations to predict dwell times and passenger flow rates (albeit with some loss of accuracy) and to examine whether the statistical significance noted is of practical significance.

Given the calibrations for boarding RATE, as discussed in the previous section, two methods of generating predictions of the number of passengers on board at a future time have been developed by making recursive calculations or by solving difference equations. Although the focus here is on the left center door, and multidoor situations are more complex, statistical techniques were used in Fritz (1) to predict the expected value of dwell time for multidoor vehicles with imbalanced queues among the doors (i.e., the likely case where one door dominates over the others in passenger count and/or passenger service times). Uneven door use can contribute significantly to the existence of greatly protracted dwell times.

Method 1

Simple recursive estimates for either univariate or multivariate regressions, regardless of whether it is a closed-form solution, are possible. For example, the basic equation that relates RATE and PASS as calibrated from the raw disaggregate data is

$$\text{RATE}_N = b_{\text{PASS}} * \text{PASS}_{N-1} + b_0 \qquad (1)$$

Adding $\text{PASS}_{N-1} + \text{RATE}_N$ and collecting terms gives a recursive relation:

$$\text{PASS}_N = (b_{\text{PASS}} + 1) * \text{PASS}_{N-1} + b_0 \qquad (2)$$

Method 2

Method 2 is a generalization of method 1 as a difference equation solution for simple cases. The difference equation exemplified by Equation 2 has a unique, closed-form solution:

$$\text{PASS}_N = (b_{\text{PASS}} + 1)^N * \text{PASS}_0 + (b_0/b_{\text{PASS}}) * [(b_{\text{PASS}} + 1)^N - 1] \qquad (3)$$

Solving for N,

$$N = \log\,[(\text{PASS}_N + b_0/b_{\text{PASS}})/(\text{PASS}_0 + b_0/b_{\text{PASS}})]\,/\log\,(b_{\text{PASS}} + 1) \qquad (4)$$

Point-Estimate Predictions

A series of point-estimate predictions were undertaken, which focused on (a) marginal rates (by using Equation 1), and (b) total passenger processing times and average rates given initial conditions of PASS_0 and REM_0 (by using Equations 3 and 4). Key load volumes (passengers per vehicle), which cover a wide range of conditions, were selected for use as boundary conditions in the predictions:

0 = vehicle is empty on arrival,
42 = all seats are occupied,
75 = mean passenger count for index scale level 4 (see section on Data Collection),
91 = estimated design capacity for pre-1951 vehicles (2.7 ft^2/standee),
95 = mean passenger count for index level 5 (see section on Data Collection), and
130 = pre-1951 vehicle crush capacity based on the MBTA's standard of 1.5 ft^2/standee.

Pairs of initial and final load volumes were selected from among these volume levels; total passenger processing times were estimated for the number of passengers indicated in each selected scenario.

Marginal boarding rates under the various conditions are displayed in Figures 2A through E. (Note, the values of RATE shown in Figures 2A through E represent the number of PASS's estimated to board in the next 10 s after reaching the load shown. In A through D, percentages within the bars refer to the relative rates for that load volume and vehicle door combination as compared with its own empty vehicle rate. In E, rates for the left center door of A are compared with the summed rates for the right-side doors of C and D. The estimated combined boarding rate capability for the right front and center doors represents a 31-62 percent greater rate than the left center door alone, as shown in E; however, this is short of the theoretical 100 percent increase of two doors over one.) As loads increase, the trend of decreasing marginal boarding rates, as compared with rates when the vehicle is empty, is evident in Figures 2A through D, both at design and crush capacities, with 49-62 percent and 70-89 percent decreases, respectively. This approach has been used to compare the efficiency of PCC left-side boarding with right-side (right front plus right center) boarding. Figure 2E shows, in a visually comparative way, the relative estimated improvement in boarding-rate productivity that results from the multiple door arrangement; this advantage ranges from 31 to 62 percent here. This is, however, short of the 100 percent increase possible without any PVI present. In reality, queues are likely to be uneven among the open doors, which reduces this advantage further when the boarding time for the more heavily used door is estimated.

Cross validation of any model is highly desirable whenever possible. It is possible to examine the compatibility of the disaggregate model calibrations with Fruin's cited LOS zones. For example, the regression equation for the left door of the pre-1951 vehicle (RATE = 13.51 - 0.0883 * PASS) can be used to predict rates at all passenger densities. Figure 3 relates summary phrases for Fruin's narrative descriptions of crowd conditions with the rates predicted from the examined passenger densities. (Note, the negatively sloped line shown in Figure 3 is RATE = 13.51 - 0.0883 * PASS, as calibrated for the left door subset of pre-1951 vehicle data. The six line segments delineated are based on summary

Figure 2. Predicted marginal boarding rates for several passenger load volumes and vehicle door combinations.

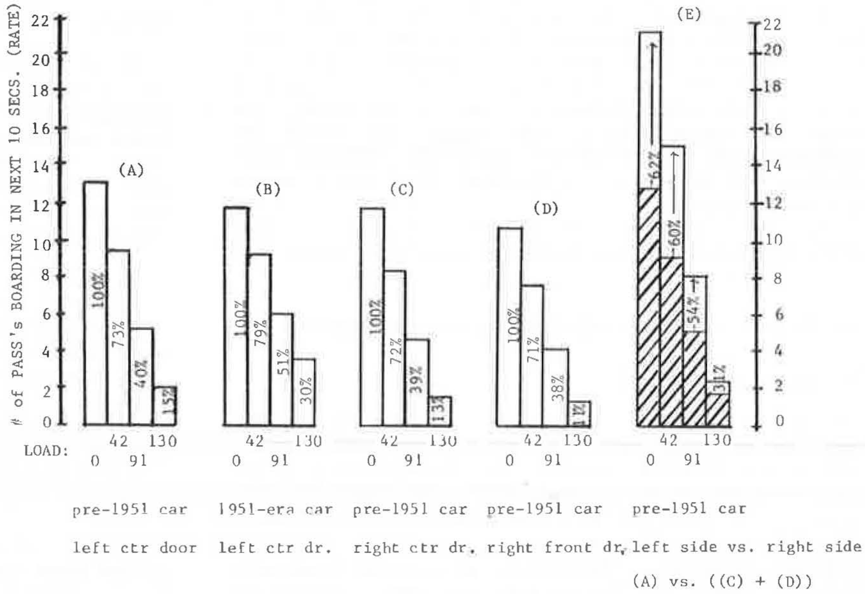
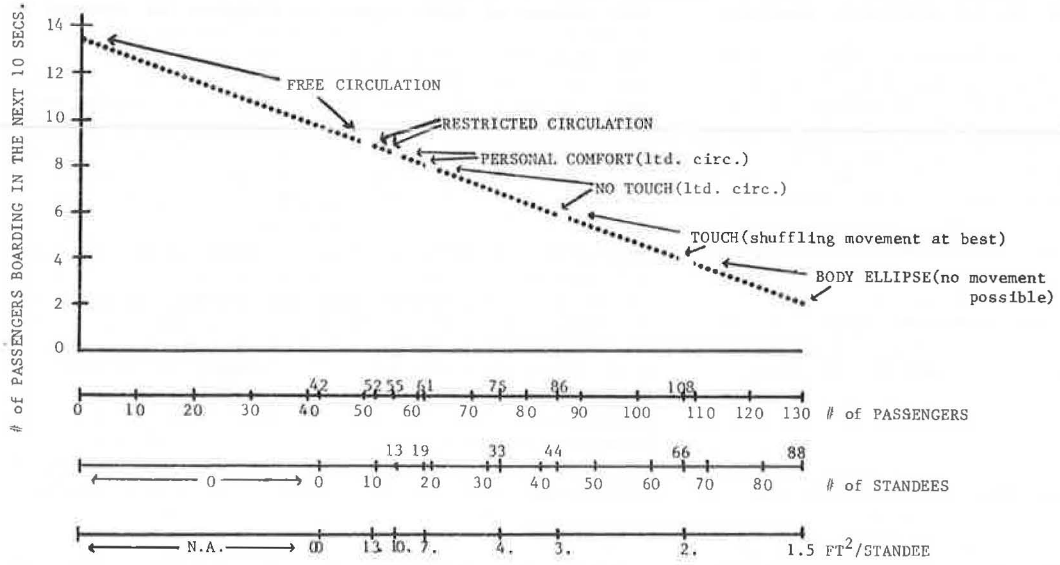


Figure 3. Comparison of Fruin's pedestrian LOS zones with predicted boarding rates.



descriptions of Fruin's pedestrian zones.) The disaggregate model predicts boarding rates that range from 13.5 for an empty vehicle to 2.0 at crush capacity--both are relative to 10-s periods. Even at crush capacity, such a relatively low rate of 2 passengers/10 s reasonably coincides with Fruin's expectation that no movement can occur at crush-capacity densities. Therefore the data-collection and model calibration procedures do indeed show desirable consistency with research conducted previously. Furthermore, the existence of numerous cases where passengers were physically unable to board the vehicle due to congestion (RATE = 0) demonstrates that movement inside the vehicle is quite difficult to achieve as crush capacity is approached.

Whereas the previous figures and tables have dealt with marginal processing rates at specified loads, Figures 4A through F show predictions of average rates for one-door situations under selected, prespecified boundary conditions. [Note, the disaggregate model used the calibration solutions of RATE = f(PASS) shown in Table 2, while the aggregate model used total time = 1.86 + 1.16 * number of boarding passes. (Note the dramatic difference between Figures 4A and G.)] These scenarios begin from the initial load as the first passenger boards and end with the final load as the last passenger succeeds in boarding. Calculations were performed by using Equation 4 to obtain total boarding times. The 1951-era vehicles have more total space and can probably accommodate a given number of passengers more easily than the pre-1951 vehicles.

Figures 5A through D compare total predicted boarding times for center doors of the pre-1951 vehicle among the three models: the disaggregate model, the aggregate model based on MBTA data, and the aggregate model that uses Kraft's data from the Newark system. The latter two aggregate models exhibit marginal reciprocal boarding rates of 1.16 and 0.9 s/passenger, respectively.

These histograms are very important. As crush capacity is approached and the boarding rate drops, the growing differences between the disaggregate and the aggregate models can be clearly seen. As might

Figure 4. Comparison of average boarding rates for three models under specific passenger load conditions.

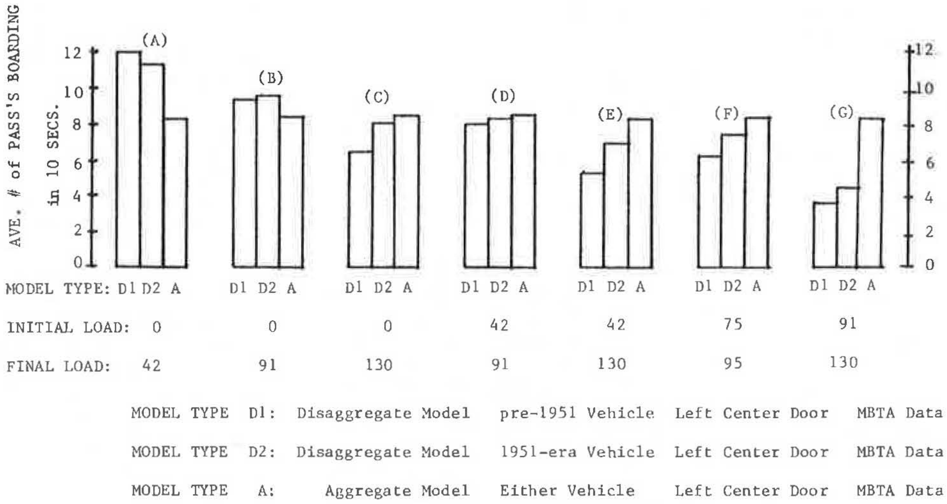
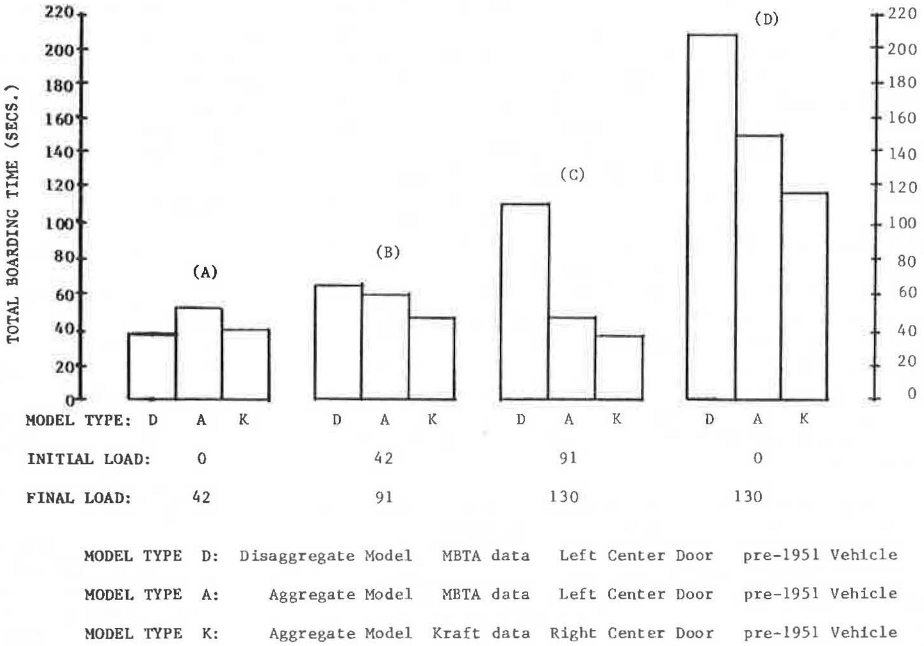


Figure 5. Comparison of total boarding time by using three models under specific passenger load conditions.



be expected, the disaggregate model is similar to Kraft's model only at low passenger loads, and diverges sharply from both aggregate models above moderate loads as congestion effects build. Also, the aggregate model based on MBTA data was calibrated with higher average loads and lower rates than was true of Kraft's model, hence the probable cause of the 25-30 percent differences in rates between these two model calibrations.

CONCLUSIONS

A framework for quantifying dwell-time effects of passenger congestion has been developed. The models presented investigate whether increasing congestion exhibits a continuously retarding effect on passenger processing. It was found that there are important differences between passenger processing under light and heavy passenger loads. The most significant variables that explain the change in observed marginal passenger processing rates were passenger load volume and queue size on the platform. The univariate regression relations shown in this paper were generalized to closed-form solutions of difference equations to permit predictions of total time in which to process given numbers of passengers. From the point-estimate predictions undertaken for varying loads, several important observations can be made:

1. As passenger load volumes exceed design capacity, the passenger processing rates are considerably lower than rates at intermediate volumes. The predictions imply that, as crush capacity approaches, passengers still waiting to board may still be able to board, but extremely slowly.
2. This study independently confirms that the boarding rates Kraft found in his Newark PCC study are likely to be highly accurate for noncongested conditions in those cases where fares were prepaid.
3. Models can be calibrated by using the disaggregate data that reflect the expectation of substantially higher dwell times under congestion than previously assumed.
4. Bulk queues have effects on passenger processing by probably somewhat hastening boarding and thus possibly reducing dwell time despite the passenger discomfort produced.

5. The location and number of doors have effects on dwell time, but not quite in proportion to their number.
6. Not only is delay time built up at the major stations, but significant additional delays downstream also can occur as people wait there to board already crowded incoming vehicles. The calibrated curves suggest that these delay-time components are major components of total travel time delays incurred.

The nature of this research would be of value to the operations planner in evaluating vehicle capacity. Such evaluation could be done prior to capital acquisition or for reevaluation of existing fleet equipment. MBTA and other operating authorities may have institutional requirements or constraints (i.e., vehicle shortages or budget cutbacks) that can unintentionally conflict with the goals of reliable, comfortable, attractive, and minimally congested service. However, an alternate crowding level recommended other than crush capacity can be judiciously chosen based on such calibrated models. Indeed, it may be worthwhile for planning purposes to set up live simulations to test whether the 1.5 ft²/standee crowding level can be achieved year round for each vehicle type in the fleet; this would show whether such a reserve capacity is truly available at those, it is hoped, infrequent times when it needs to be called on. Based on this research, and for reasons other than for passenger comfort, a strong argument can be presented that a reasonable upper limit of capacity, for use in daily operations, occurs in the vicinity of the so-called design capacity of 2.7 ft²/passenger standee (or 91 passengers on board the pre-1951 vehicle). Vehicles with daily loads that approach crush capacity are unlikely to provide the desired passenger throughput and vehicle turnaround times necessary for service reliability. Other reasons behind support of the design capacity recommendation, in at least the PCC vehicle case, are drawn from the figures and tables:

1. The scattergrams of the raw data (Figure 1) show a distinct drop in the boarding rate above the 70-80 passenger load mark.
2. The Fruin pedestrian approach suggests that limited circulation is still possible at 3 ft²/standee, which corresponds to 86 passengers on board, but such that circulation deteriorates sharply at higher densities.
3. The calibrated equation for boarding rates suggests that, at design capacity, reasonable boarding rates in the vicinity of about 50 percent of rates where empty seats are available are still possible. Although the particular range of densities most relevant in choosing a desirable and practical vehicle capacity may be different for each distinct vehicle design and required system reliability, this approach is relevant to each vehicle design for both interior layout and door access geometries.

This research provides a small but valuable contribution in the understanding of PVI as it relates to transit and passenger service times and provides a foundation for further research in the high-congestion human factors area. Insights gained from the dynamics of PVI and the potential integration of this modeling approach into simulations of service and reliability could allow for models of significantly greater realism in travel-time prediction and vehicle bunching analysis, as well as for vehicle acquisition planning for systems where passenger congestion is anticipated. Furthermore, greater awareness on the part of operations personnel of the magnitude of problems caused by congestion may, in the short term, lead to more reliable service at no additional cost to the public. Models such as those developed here in the alternative models may, by comparing relative boarding rates, provide a means for evaluating vehicle accommodation of passengers within the upper ranges of their prespecified capacity. Variables in vehicle design such as door size, door number, stairwell geometry, or interior layouts could be observed in real-time mock-up simulations and compared on a cost-benefit basis prior to fleet acquisition.

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Train Crew Reduction for Increased Productivity of Rail Transit

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Labor costs have become the dominant portion of operating costs for transit agencies. Efforts to increase productivity of operating labor have been particularly successful on rail transit systems. For example, development of high-capacity articulated cars, provision of separated rights-of-way, and introduction of self-service fare collection have resulted in an approximately 20-fold increase in productivity of light rail transit systems. Possible methods for reducing train crews on existing systems that have obsolete operations are analyzed. Their implementation is shown to be feasible and, in many cases, not necessarily complicated. It is shown that although the recently built rail transit systems (e.g., Lindenwold Line, San Francisco's Bay Area Rapid Transit, and Atlanta's Metropolitan Atlanta Rapid Transit Authority) have one-person train crews and thus high productivity, most older streetcar, rapid transit, and regional rail systems still have obsolete and inefficient labor practices. A systematic analysis shows that, on many existing transit systems, the productivity of operating labor can be substantially increased through modest efforts. The greatest potential benefits from the introduction of modern operating methods exist on regional rail systems and, to a lesser extent, on existing rapid transit systems. Cooperation of labor unions should be obtained by retaining jobs through increased service frequency or by passing on a portion of the savings to the operating employees in the form of increased wages for increased duties.

The focus of this study is on the labor productivity of rail transit operations. Rail systems have the potential to achieve a high level of labor productivity through the use of modern operating practices. High productivity translates into either low costs for a given volume of transit service or large volumes of service provided for a given cost.

Still, in the United States, one can find a wide range of practices: from a one-person crew per 10-car rapid transit train [Bay Area Rapid Transit (BART)] to a three-person crew on 3-car trains of short streetcars, or, until recently, on 4-car rapid transit trains (both in Boston).

The purpose of this study is to systematically review the issues that determine crew sizes in rail transit, to review the current practices in different cities, and to examine the possibilities of reduction of train crews, particularly on existing transit systems.

RAIL TRANSIT MODES AND CREW DUTIES

Mode Categories Defined by Transit Unit Crew Sizes

Light Rail Transit

Light rail transit (LRT) is electric rail transit that consists of one- to three-car transit units (TUs) that operate on partly or fully separated rights-of-way (and, in some cases, on streets). Stations are generally unattended, and only manual driving is possible because of grade crossings or street running.

1. LRT-1: There is one crew member (the driver) per TU. The driver supervises fare collection, checks flash tickets, or allows free entry (self-service system). Alternatively, the driver may sell tickets to those passengers without prepaid ones. The driver controls doors, supervises passenger boarding, and announces stations. Vehicles may be large (articulated cars) and, in some cases, TUs may consist of two to four cars.
2. LRT-2: There are two types of systems in this category (a) driver plus conductor, where the driver has no other duty except driving; the conductor controls fare collection, operates rear doors, supervises passenger boarding, etc. (there are no North American operations of this type); and (b) multiple unit (MU) operations, where the driver is in the lead car and an attendant is in each trailing car; the attendants perform all duties for their cars that the driver does for the lead car except driving (such systems normally operate as MUs for part of the day and as LRT-1 for the rest of the day).

Rail Rapid Transit

Rail rapid transit (RRT) includes rail transit systems with fully controlled rights-of-way (category A) and stations; therefore, fully automated driving is theoretically possible. TUs consist of up to 10 cars. All stations are either attended or have automatic fare collection. Fares are collected in stations before the passengers enter the platforms. On-board fare collection is uncommon (e.g., off-peak on some systems). Platforms are high level.

1. RRT-1: The driver is the only crew member. In addition to driving, this crew member controls the doors and can announce stations via a public address system. On a few systems (Cleveland, Skokie in Chicago), fares are collected by the driver. RRT-1 systems are often, but not always, equipped with automatic train control.
2. RRT-2: Crew consists of the driver plus one or more other persons whose main duty is to control the doors. The extra crew member or members may also collect fares at low-volume stations or during off-peak periods.

Regional Rail

Often called commuter railroads, regional rail (RGR) has a great variety of operating characteristics. Their stations can be attended or unattended, but there is usually free access to the platforms. Platform heights may be either all low, all high, or mixed (some low and others high level).

1. RGR-1: In a low-volume operation, the driver may be required to collect tickets in addition to controlling the doors and driving. This category is extremely rare; there are no examples in North America.
2. RGR-2: In this system, there is one driver plus another crew member, who may primarily control doors, collect tickets, or both. Most modern RGR systems operate with two-person crews. Some operate as RGR-2 during off-peak periods when one-car trains are used; at other times (with MU operation), more crew members may be required.
3. RGR-3: In the United States, systems that operate under class I railroad rules often have three or more crew members. Doors are often manual and may have traps to enable operation at both low- and high-level platforms. Tickets are sold either at stations or by conductors. Every passenger is checked for fare payment by a conductor.

The following table summarizes the categories given above:

Basic Mode	Crew Size	Category Designation
Light rail transit	1	LRT-1
	2	LRT-2
Rapid transit	1	RRT-1
	2	RRT-2
Regional rail	1	RGR-1
	2	RGR-2
	3	RGR-3

Definitions of Crew Duties

A detailed examination of operating practices on most rail transit systems, which includes all rail modes, has shown that TU crew members perform a maximum of 17 duties, which are shown in Table 1, and are classified by their applicability to each mode. The list below explains crew members' duties in more detail:

1. Supervising doors. Passenger boarding and alighting can be observed in the following ways: (a) a crew member stands on the platform or looks from a train window, (b) driver looks from the window of the cabin, (c) station attendant, or (d) there is no supervision, but there is a warning for passengers that doors will close and all doors have sensitive edges to prevent catching a passenger. These methods are adequate for all systems with high-level platforms. LRT and RGR systems on which vehicles have high first steps require on-location supervision and assistance to ensure safe boarding and alighting.
2. Closing doors. Manually operated doors on transit (RGR) vehicles are usually not closed after every station. Automatic doors are closed from a single control point or automatically. Closing from a central location comes usually from a driver's cab, either in the first or in some other car. Automatic closing comes after a predetermined standing-time interval. In either case, a voice warning or a buzzer warns passengers before door closing. Thus, door closing can be done by (a) a crew member (nondriver), (b) the driver, or (c) automatic pretimed control.
3. Fare collection. Cash from passengers can be collected by (a) automatic machines that issue fare cards to be used for entrance or to be checked on board, (b) fare boxes or turnstiles, (c) cashiers, (d) crew members, (e) drivers, or (f) prepaid tickets (monthly commuter tickets, passes).
4. Fare control. Fare payment can be checked by (a) automatic gates activated by coins, tokens, or fare card; (b) crew on a regular basis, usually during travel; (c) driver during passenger boarding or alighting; or (d) controllers on a spot-check basis.

Table 1. Duties of rail transit crew members by mode.

Duty	SCR and LRT	RRT	RGR
Driving	x	x	x
Train inspection			x
Reporting at terminal			x[a]
Coupling and uncoupling	x	x	x
Communications with control center	x[a]	x	x
Announcements	x	x	x
Opening doors	x	x	x
Supervising doors	x	x	x
Closing doors	x	x	x
Moving traps	x		x
Signaling departure	x	x	x
Changing seats			x
Passenger information	x	x	x
Fare collection	x		x
Fare control	x	x	x
Safety and security	x	x	x
Emergencies	x	x	x

Note: SCR = streetcar.

[a] Few applications.

In order to reduce personnel, two alternatives are considered:

1. Keeping two-person train crews (typical for older RRT systems) and eliminating station personnel (Cleveland uses this practice during off-peak hours), or
2. Retaining station personnel but reducing train crews to one member (typical for several new RRT systems, such as BART and Washington, D.C., Metro).

The basic factor of selecting between these two alternatives is the number of stations (and their design, which may require more than one station attendant) and the number of trains in operation.

PURPOSES OF TRAIN CREW REDUCTIONS

The percentage of total operating costs going to labor indicates the importance of productivity. In most transit agencies, labor costs have grown to 60 to 80 percent of total operating costs, despite the realization that the financial condition of the transit system could be enhanced by improving the productivity of the operating personnel.

Transit operators in U.S. cities were among the first in the world in the 1930s to introduce one-person crews on all street single-vehicle transit systems: streetcars, trolleybuses, and buses. Several other developments occurred in the meantime that actually decreased productivity in street transit modes. These were

1. Replacement of streetcars by buses with approximately 20 percent lower capacity;
2. Loss of separate streetcar rights-of-way on many lines, which resulted in lower transit operating speeds; and
3. Increased street congestion, which also decreased operating speed.

A drastic increase in rail transit labor productivity occurred only when new RRT systems were built, starting with the Lindenwold Line in Philadelphia. Figure 1 shows transit operating personnel productivity as a function of crew size for the three modes: LRT, RRT, and RGR.

The benefits from reduced crew sizes are basically economic (reduced costs), and they can be translated into the following forms:

1. Reduce the number of operating personnel and maintain the same service. Benefit: reduced operating costs.
2. Retain the same operating personnel but change the crew members released from duties into security officers. Benefit: increased security.
3. Retain the same operating personnel, but split trains into half-size units (e.g., one eight-car train into two four-car trains) and provide service with double frequency at the same cost. Benefit: increased level of service.

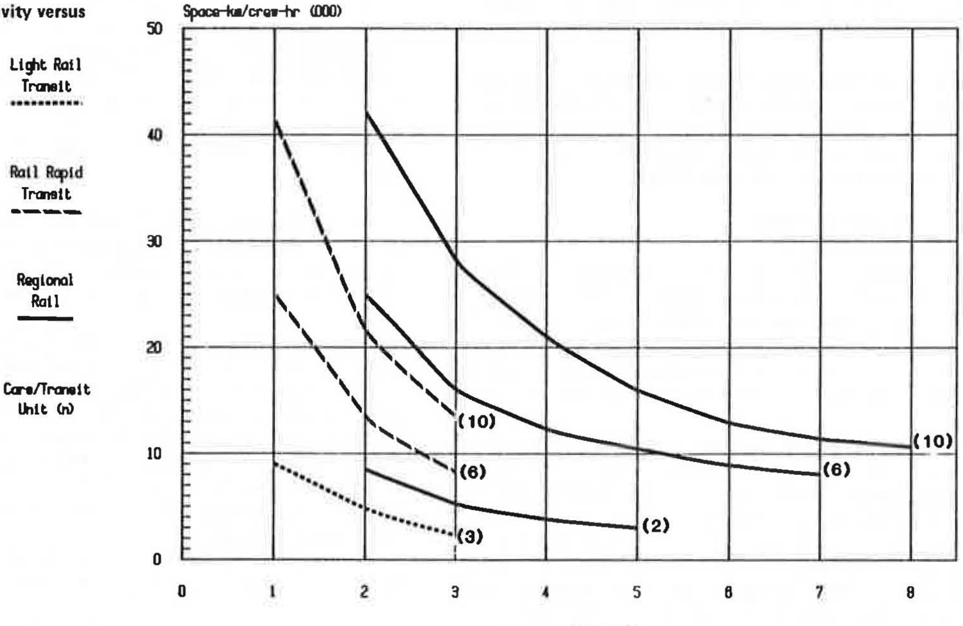
In most cases, a combination of two or three of these benefits is the best solution.

CREW REDUCTION ON LRT SYSTEMS

No transit mode has made such remarkable progress in increasing labor productivity in a span of only approximately 25 years (between the mid-1950s and the late 1970s) as has been the case with streetcars and LRT. A review of LRT rolling stock and types of operation (characteristic for different stages of development) is presented in Figure 2. It should be mentioned that virtually all this progress took place in West European countries; the practice of using longer TUs has had a much longer tradition in those countries than in North America. It has been only in recent years that several cities in North America have adopted the latest advances in LRT system technology and operations from West European countries.

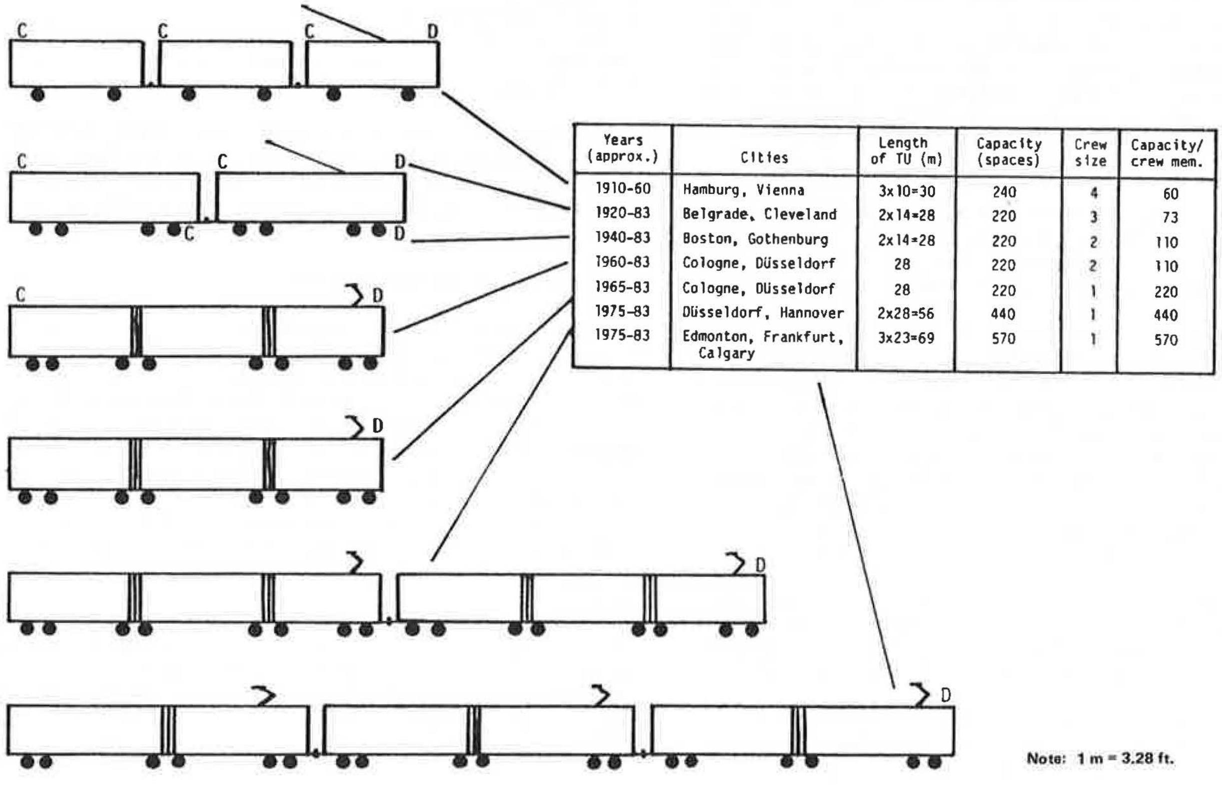
In addition to the development of articulated cars and construction of upgraded rights-of-way, a major breakthrough for LRT labor productivity oc-

Figure 1. Operating productivity versus crew size.



Note: 1 km = 0.62 mile.

Figure 2. Increased labor productivity on SCR and LRT through rolling stock and operational innovations, 1950-1980.



Years (approx.)	Cities	Length of TU (m)	Capacity (spaces)	Crew size	Capacity/ crew mem.
1910-60	Hamburg, Vienna	3x10=30	240	4	60
1920-83	Belgrade, Cleveland	2x14=28	220	3	73
1940-83	Boston, Gothenburg	2x14=28	220	2	110
1960-83	Cologne, Düsseldorf	28	220	2	110
1965-83	Cologne, Düsseldorf	28	220	1	220
1975-83	Düsseldorf, Hannover	2x28=56	440	1	440
1975-83	Edmonton, Frankfurt, Calgary	3x23=69	570	1	570

Note: 1 m = 3.28 ft.

curred in the method of transit operation. During the 1960s, a full self-service fare-collection system on many systems was introduced.

Clearly, all existing systems that operate four-axle cars as single vehicles cannot be made more labor efficient. One driver on each such vehicle is the absolute minimum crew size that can ever be achieved. However, there are two methods by which labor productivity can be increased:

1. Introduction of higher-capacity cars, such as six- and eight-axle articulated ones; this has already been done in Boston, Edmonton, San Francisco, Calgary, Cleveland (Shaker Heights), and San Diego; and
2. Operation of the second and third cars in LRT trains without crews, which would be beneficial for new and existing systems that operate TUs with more than one car, such as Boston, Buffalo, Cleveland, Philadelphia, Pittsburgh, and San Francisco.

CREW REDUCTION ON RRT SYSTEMS

There are two basic types of RRT systems in North America with respect to crew sizes. The systems that were in existence before 1969 have two-person crews: a driver and a conductor. Basically, the conductor opens, controls, and closes doors; signals to the driver; and has no duties during the travel of the train.

The second group of RRT systems consists of those that started operations since 1969: the Lindenwold Line in Philadelphia; BART in San Francisco; Washington Metropolitan Area Transit Authority (WMATA) in Washington, D.C.; and Metropolitan Atlanta Rapid Transit Authority (MARTA) in Atlanta. All of these systems have crews that consist of one person--the driver--who performs all the duties: controls the train (which is in most cases automated); opens, supervises, and closes doors; and communicates with the control center.

The Cleveland rapid transit system, which opened in 1955, applies great flexibility in crew employment. It operates with both one- and two-person crews, depending on the time of day. During peak hours, stations have attendants and trains operate with two-person crews, with the conductor only controlling doors. During off-peak hours, most stations are not attended, with fares collected on trains. Two-car trains have two-person crews, one-car trains have the driver only, who also collects fares.

The major obstacles to one-person operation that will be encountered on most existing RRT systems are visibility of all doors to ensure their safe closing and maintenance of security and public perception of safety.

Following is a case study of the Market-Frankford subway, which is an elevated line in Philadelphia. The Market-Frankford RRT line in Philadelphia has many physical features and operating practices typical of most other older RRT systems. The line is a conventional RRT line with broad-gauge track, which operates on an elevated structure in west Philadelphia, in a subway through the central business district (CBD), and on an elevated structure again to the Bridge Street terminal in northeast Philadelphia.

There are 28 stations on the line. Twenty-three have side platforms, three have center platforms, and the two terminal stations combine the two configurations, i.e., they have both side and center platforms.

The trains currently operate with two-person crews: a driver and a conductor. The driver is positioned in a cabin at the head of the train on the right or outer side of the vehicle. The conductor, who is responsible for the operation of the doors, is positioned in another cabin along the train and changes cabins between stations with side and center platforms to see the respective doors.

The possibility was explored that trains on the Market-Frankford line be operated with only one crew member--the driver--on board each train. In order to operate with this system, the driver would have to assume all on-board duties. At the same time, a consistent level of service and equally safe operation as with two-person crews must be ensured.

To enable the driver to operate the train doors, the restrictions of location must be resolved. Unlike the conductor, the driver is located at a fixed place on the train--the front right corner of the first car--and cannot move from that point. The physical problems that must be solved so that the driver can perform door control from that location are

1. Adequate visibility for observation of boarding and alighting along both sides of the train and up to the maximum length of the train, and
2. Physical control of all doors from the cabin.

The driver can see all doors on the right-hand side by leaning out of the window. This is the case at 23 stations. At the three stations with center platforms, signals would have to be installed by which a person on the platform (or in the cashier's booth via closed-circuit television) would indicate to the driver when to close the doors. Currently, at the two terminals, a station attendant is already observing the doors.

Consequently, the change from two- to one-person trains on this line would require

1. Adding door control for the opposite (left) side doors in the driver's cabin,
2. Installing a signal system (and, possibly, closed-circuit television) at three stations,
3. Adding one platform attendant (if television is not installed) at each of the three stations with a center platform, and
4. Withdrawing half of the crew members from operations; this amounts to approximately 30 positions during peak hours.

Indications are that, although conditions (station design, operating methods) vary among cities, most older systems that currently operate with two-person crews could eliminate the second person with modest efforts.

CREW REDUCTION ON RGR SYSTEMS

Regional rail systems started their operations as special services of long-distance railroads. In most cities they are still operated in that manner. Railroad managements have considered RGR services as a separate duty that they, particularly in recent decades, do not want to have. Transit agencies, on the other hand, have little jurisdiction and little operating coordination with them. This situation made a drastic shift on January 1, 1983, with the withdrawal of the Consolidated Rail Corporation (Conrail) from many northeast commuter rail operations.

In spite of this increasing need for their services, RGR systems have recently been experiencing mounting financial problems. The main cause of these problems is that these systems in North American cities largely operate under obsolete, labor-intensive practices. Three major problems can be identified:

1. Overstaffing: Train crews consist of two to as many as seven (exceptionally even more) persons. In addition to the driver, there are usually a considerable number of other positions, many of which are given nebulous titles (fireman, brakeman, flagman).
2. Distribution of duties: Typically, each crew member has strictly defined duties and does not perform anything else. Often two or more persons do jobs that are performed at different times. Hence, these jobs could be handled by only one person.
3. Excessive wages: Crews on RGR systems receive higher wages than transit workers on similar and other much more difficult jobs (e.g., driving buses through congested urban streets) because they usually belong to national railroad unions. Moreover, allowances for split shifts and overtime are often high. Finally, there are a number of artificially imposed bonuses that have no rational basis.

The Media-West Chester line, 1 of 13 RGR lines that serve the Philadelphia metropolitan area, extends from center city Philadelphia in the westward direction to West Chester. It is 44.2 km (27.5 miles) long and has double track from Suburban Station in center city Philadelphia to Elwyn, and single track from Elwyn to West Chester. There are 27 stations on this line, with an average distance between them of 1.64 km (1.02 miles). All stations along the line have low platforms except two--Penn Center and 30th Street Station.

The line currently operates with a minimum crew size of three (which consists of one engineer and two trainmen) for one-car trains, up to a maximum crew size of seven (one engineer and six trainmen) for six-car peak-hour trains. Crew size varies depending on ticket-collecting requirements but, in general, an additional trainman is required for every additional two cars in the consist above the basic one-car, three-person operation.

The four major duties now performed by on-board train personnel are driving, opening and closing doors and moving traps, supervision of the boarding and alighting process, and fare collection. Any plan that proposes to reduce on-board crew requirements must provide alternative methods for performing the last three duties: operation of the doors and traps, supervision of boarding and alighting, and fare collection. Currently, at least one crew member is required to supervise boarding and alighting at each set of two adjacent doors for the following reasons, which are imposed by car and station designs:

1. Low-level platforms and high steps, which combine to make boarding difficult and slow;
2. The need to ensure that all passengers are within the passenger compartment before the train has started; and
3. The inability to fully close the vestibule, which leads to the possibility that a passenger may fall from the train.

The largest amount of time spent by the crews is related to fare-collection tasks. The current fare-collection method is similar to that of conventional railroad practice where the conductor must inspect and punch each ticket.

Five alternative methods of train operation for the conditions on this line will be compared in this section. These alternatives are

1. Current method;
2. Partial self-service fare collection with moderate crew reductions;
3. Full self-service fare collection with modifications to vehicle doors, which make operation with two-person crews possible;
4. Full self-service fare collection with construction of high-level platforms, which allows operation with two-person crews; and
5. Fully enclosed stations with automatic fare collection, which enables one-person crews.

Alternative 1: Current Method

The method of current operation (described above) was developed for operating conditions in the early 1900s, which have drastically changed since that time: labor wages have increased much faster than other cost components, numerous technological inventions have become available, requirements for higher speeds have increased, and so on.

The primary disadvantage of the current operating method is that it is the most labor intensive of all alternatives. The use of large crews combined with the high wages of railroad workers (they are one of the highest paid blue-collar groups) results in extremely high operating costs for this transit mode.

Alternative 2: Partial Crew Reduction

Alternative 2 uses elements of both the current and the self-service fare-collection methods to ease the task of ticket collection and inspection. This allows the reduction of train crews to the minimum required for safe supervision of boarding and alighting of passengers and a reduction in station agents.

The major capital expense is the purchase of ticket vending and cancellation machines for some stations. Because no major modification would be required in vehicles or stations, this alternative could be implemented in a relatively short time.

Because low-level boarding and alighting would be retained with this alternative, and because boarding and alighting requires the presence of a crew member for safety, the crew reduction would necessitate that a smaller number of doors be opened. Each crew member would supervise two doors on close ends of two adjacent cars. It should be noted that passengers in cars in the center of the trains with four or more cars would not be able to enter or exit through doors at one end of the car.

Because both 30th Street and Penn Center have high-level platforms, all exits could safely be used for unloading without crew members supervising them. However, this would require remote door control. Because this alternative requires no modifications in vehicles or stations, it can be used as an intermediate step before full implementation of self-service fare collection. Compared to the current method of fare collection, alternative 2 offers the following advantages and disadvantages:

1. Advantages: (a) reduction in crew requirements by one to two crew members per train; (b) reduction in station ticket agent requirements because tickets could be purchased from vending machines or many off-line locations; and (c) provision of a system of checking the proper zone and destination for the ticket; and
2. Disadvantages: (a) requires capital and maintenance cost for installation of ticket vending and cancellation machines, and (b) passengers will not be able to board and alight at all train doors because of reduced crew size.

Alternative 3: Vehicle Modifications

Alternative 3 requires modification of doors so that they can close regardless of the position of traps. This involves long doors that would extend down to the level of the lowest fixed step rather than only to the car floor, as is currently the case. This modification would permit two operational improvements. First, vestibules in cars would always be enclosed during train travel, which eliminates the possibility of passengers falling from a moving train. Second, combined with a few other changes, this modification would enable the boarding and alighting process to be carried out without direct supervision by a crew member.

In conjunction with a self-service fare-collection system, this method of train operation could reduce crew requirements for all trains to two: the driver and the conductor. The driver, in addition to the traditional duty of driving the train, would open and close doors and announce upcoming stations. Operational difficulties would be encountered for specific locations but, through an examination of alternatives, it is believed that these obstacles would not be insurmountable. Compared to the current operation, this alternative method has the following advantages and disadvantages:

1. Advantages: (a) reduction in train crew sizes, ranging from one to five persons; (b) reduction of the number of station agents (due to introduction of machines and sales through other outfits); (c) increased safety due to closed doors during train travel; (d) reduced underpayment of fares (currently undetectable in many cases); and (e) better station announcements via a public address system; and
2. Disadvantages: (a) requires a major investment in door retrofitting, (b) requires investment in ticket vending machines, and (c) reduces assistance to passengers during boarding and alighting.

Alternative 4: High-Level Platforms

Alternative 4 is similar to alternative 3 with the exception that safe boarding and alighting would be accomplished through construction of high-level platforms rather than through door modifications. The current door and step arrangement would not need to be modified, as the trap would remain in the lowered position, which fully encloses the vestibule area. Again, door control is accomplished by the driver while the conductor would assist in door supervision and departure control. The self-service fare-collection system remains unchanged from the previous alternative.

Two options are available for the construction of high-level platforms along the Media line:

1. Raising the platform level at every station from Philadelphia to West Chester, or
2. Raising the platform levels only at stations on the heavily used portion of the line from Philadelphia to Elwyn; the light passenger loads between Elwyn and West Chester can be handled by two-car trains, which are small enough for the trap and door supervision to be handled by one conductor.

Although this alternative accomplishes the same objectives as alternative 3, construction of high-level platforms has important impacts on other aspects of the operation, including passenger comfort, operating speeds, and freight service.

In comparison with the current method of operation, construction of high-level platforms along with self-service fare collection offers the following advantages and disadvantages:

1. Advantages: (a) reduction in train crew sizes, ranging from one to five persons; (b) reduction in the number of station agents; (c) safer and more comfortable boarding and alighting; (d) faster boarding and alighting, which results in higher operating speeds and reduced vehicle requirements; and (e) reduced underpayment of fares; and
2. Disadvantages: (a) requires a major investment in high-level platforms, (b) requires investment in ticket vending machines, and (c) restrictions on freight car size.

Alternative 5: Fully Automatic System

Alternative 5 incorporates a fully automated fare-collection system. Passengers would purchase tickets from automatic vending machines and enter and exit the station area through automatic turnstiles. No on-board train personnel are required for fare-collection tasks and train crews could be reduced to one. This system would require rebuilding of all stations to provide a separate, enclosed paid area.

Comparison of Alternatives

The final alternative should be selected on the basis of the most favorable economic and operating results and service characteristics that affect passengers. To make a clear comparison of these on the basis of the preceding analyses, the major items that differ among the alternatives are summarized in Table 2.

Conclusions and Recommendations for RGR Operations

Each of the alternatives provides a method of bringing about reductions in on-board crew requirements. Because Philadelphia has an RGR system that includes low-level platforms and doors that do not fully enclose vestibules for low-level boarding, it presents a worst case for bringing about these changes. RGR systems in Chicago, New York, parts of the New Jersey Northeast Corridor Line, and San Francisco incorporate at least one of these features and would be easier to convert than the Philadelphia system.

It is also important to consider the impact of the Center City Commuter Connection on the alternatives. This project, to be completed in 1984, will connect the former Penn Central lines (including the Media line) with the Reading lines. Therefore, a change in fare-collection and passenger loading procedures on the Media line will require a corresponding change on the Reading line with which it will be connected. The lines on the two systems are similar, and it is possible to accomplish this without major difficulties. Successful implementation of one of these alternatives can lead to its introduction on the remaining RGR lines.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The current conditions on many rail transit systems in North America are, in some ways, illogical. The rail mode, which potentially has by far the highest labor productivity and therefore the lowest unit operating costs, does not fully use that potential. Although the operations of several rail transit systems (Lindenwold Line, BART, MARTA) clearly indicate that a high level of automation is possible, there are still systems of all modes (LRT, RRT, and RGR) that have the same intensive labor use as they had in 1900-1920 when the cost of labor was much lower and technology much more primitive.

Table 2. Comparative analysis of alternatives 1-5.

	Comparison Items						Reduced Assistance to Passengers for Boarding and Alighting		
Alternative	Crew Size	Vending Machines	Cancellation Machines	Vehicle Modification	High-Level Platforms	Station Rebuilding	Advantage	Disadvantage	Cost ($000 000s)
1	3-7	None	None	None	None	None	–[a]	–[a]	0
2	2-5	Low-medium	Low-medium	None	None	None	Fewer station agents Positive control of zone fares	Fewer doors open Requires maintenance of vending and cancellation machines	2-4
3	2	High	High	High	None	None	Fewer station agents Travel with closed doors (higher safety) Reduced fare evasion	Reduced assistance to passengers for boarding and alighting Requires maintenance of vending and cancellation machines	4-6
4	2	High	High	None	High	None	Fewer station agents Reduced fare evasion Faster and safer boarding and alighting Reduced vehicle requirement	Restrictions on freight service Requires maintenance of vending and cancellation machines	8-12
5	1	High	High	None	High	High	Fewer station agents Reduced fare evasion Faster and safer boarding and alighting Higher operating speed Reduced vehicle requirement	Restrictions on freight service Requires maintenance of vending and cancellation machines	12-15

[a]The current base system.

The study shows that train crew reductions can decrease operating labor costs significantly, in most cases to nearly 50 percent on some LRT and RRT systems and to 30 percent of the current costs on some RGR systems. Most streetcar and LRT systems cannot decrease their crews, because they already have one-person operation. But those with MU operation can reduce crew size by the introduction of self-service fare collection (following the examples of Edmonton, Calgary, and San Diego). Older RRT systems can reduce their crews to one person with minor changes and limited investment.

RGR systems can realize by far the greatest potential in savings through crew reductions. They must, however, undertake somewhat more extensive changes, such as redesign of car doors, construction of high-level platforms, or introduction of self-service fare collection. Improvements in productivity require certain planning and capital investments, but these would be easily compensated by the large savings in operating costs from crew size reductions. Because of special operating features of the RGR mode, it is not expected that these crews can be reduced below two members.

Technical problems of the proposed changes are in most cases minor. Some measures required on a few RGR systems are an exception. The major obstacle in many cases is the opposition of labor unions. The cost of this opposition is, however, so high that the existence of these modes is being threatened. Time for major changes and modernization has come; they cannot be delayed much more.

It is recommended that all transit operating agencies that potentially can benefit from crew reductions immediately initiate activities along two lines: (a) planning of the physical and operational changes needed for crew reduction, and (b) negotiations with the labor union or unions and search for cooperation in the needed modernization.

There are several measures that can make crew reductions more acceptable to labor unions. They are

1. Stipulation that most of the benefits from crew reduction are passed on to the public through higher frequency of service (so that the same number of employees is retained); this is applicable to off-peak RRT operations;
2. Reassignment of the freed crew members to other duties; and
3. Increased wages (e.g., 10-15 percent) for the reduced crew members; thus, the savings would be shared by the agency and its employees.

In conclusion, the study has clearly shown that, on rail transit systems that currently have larger crews than modern operating practices require, improvements of productivity are usually possible. Relatively small efforts to reduce crews can often bring considerable and permanent saving without service degradation. The alternative to such actions may, in some cases (RGR), be catastrophic, e.g., discontinuance of services. It is therefore recommended that UMTA strongly support transit and railroad agencies interested in this problem by disseminating information on possible methods for train crew reduction and by assisting with labor negotiations. Such action would be in the public interest.

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