TRANSPORTATION RESEARCH RECORD 817

Rail Transit and Terminals

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1981

Transportation Research Record 817
Price $6.20
Edited for TRB by Mary McLaughlin

mode
2 public transit

subject areas
11 administration
12 planning
16 user needs
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54 operations and traffic control
55 traffic flow, capacity, and measurements

Library of Congress Cataloging in Publication Data
National Research Council (U.S.). Transportation Research Board. Meeting (60th: 1981: Washington, D.C.)
Rail transit and terminals.

(Transportation research record; 817)
Reports presented at the 60th annual meeting of the Transportation Research Board.
1. Street-railroads–United States–Congresses. 2. Subways–United States–Congresses. I. Title. II. Series.
TE7.H5 no. 817 [HE4451] 380.5s 81-19031
ISBN 0-309-03258-X ISSN 0361-1981 [388.4'2'0973] AACR2

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Abridgment

Project 21: A Practical New Intermediate-Capacity Rapid Transit System

L.K. EDWARDS

Project 21 is a rail transit system that incorporates most of the features of classical rail rapid transit but is optimized for elevated placement and for intermediate-capacity applications. An overview of the system is presented. The novelty of the system is concentrated in the slender guideway, car suspension, and a practical branch for two-way traffic. All of these, and the associated third-rail power distribution, have been refined in recent years and are considered ready for construction of a prototype. Commercial service in a 55-mile/h regional network could start in five years. The potential benefits are widespread use, extraordinary safety and reliability, quick installation, very low capital cost, and moderately low operating cost.

Project 21 is a new transit system for metropolitan areas that have identified the need for rail transit but are unable to obtain the necessary funds. In most respects, Project 21 is a form of rail rapid transit in that it provides

1. The energy efficiency and all-weather reliability of steel on steel;
2. The speed and operating efficiency of an exclusive guideway, level boarding, and prepaid fares;
3. The environmental and reliability advantages of electric power;
4. A switch generally like a railroad switch;
5. Cars that can run individually or be coupled into trains; and
6. A guideway suitable for two-way traffic with occasional grade-separated branches.

To provide these features at greatly reduced cost, Project 21 departs from classical rail rapid transit in these respects:

1. It is scaled for capacity in the range of 10 000 to 20 000 passengers/h.
2. It is specially adapted for elevated placement to avoid the huge cost of tunnels.
3. It has radically reduced guideway dimensions to make the elevated line acceptable along streets and boulevards in sensitive areas.
4. Station dimensions are also radically reduced.
5. It has a unique branch arrangement, compact enough for placement above the streets.
6. It features standardized and modular guideway, stations, and branch elements to permit factory production, quick installation, and flexibility for the future.

The system also has other assets in terms of rider appeal and safety that will be discussed in this paper.

BACKGROUND

Project 21 arose out of my search for a practical, intermediate-capacity transit system, beginning in the mid-1960s. Active work on this system began in 1971 with the discovery of a practical means for branching of elevated two-way traffic. Early refinement of the concept was done by a team at Lockheed. The guideway design was further refined in collaboration with Lloyd H. Donnell, the American Bridge Division of U.S. Steel, and a major supplier of electrical distribution hardware. Specific applications were worked out for a network in Los Angeles and a smaller layout at the Los Angeles International Airport. The system is proprietary, being covered by U.S. patents 3,890,904 and 253,750.

GENERAL SYSTEM ARRANGEMENT

The cornerstone of the Project 21 system is the novel guideway arrangement, which uses a triangular section that carries the transit cars on each side, as shown in Figure 1. Support and guidance for the cars are supplied by means of a slightly modified standard rail fastened at the lower corner of the steel beam. This rail also takes all traction and braking forces and serves as the electrical ground. To prevent cars from tipping away from the beam, there is a unique upper rail, which is integral with the apex of the beam. The power-supply "third rail" is beneath, and protected by, this upper rail.

CARS

Cars for the system are about the size of a small city bus and have seats for 22 passengers and standing room for about 20 more (crush load). The "lead car" has provision for an operator using conventional controls. This car can operate alone in off-peak hours and is supplemented by "B cars" in rush hours. Trains could be any length desired, but the current system definition calls for a maximum of four-car trains in order to limit the length and cost of stations. Figure 2 shows the general arrangement of the lead car. As indicated in Figure 3, the B car is similar except that it has a passageway in front and no operator position.

The inboard side of the car is shown in Figure 4. It has folding double doors for entrance and exit at the station and two windows. The trucks are located in recesses near the car ends and are removable from outside. Each truck comprises a 600-V motor, gear drive, brake, and a single, steel-rimmed wheel. The truck also has integral hooks to surround the lower railhead and thus prevent derailment; the wheels are barely visible beyond these hooks.

Figure 5 shows a section through a car in the seat area. The width of the forward-facing double seats is typical for rail rapid transit; the same is true of the aisle width and headroom.

CAR-TO-GUIDEWAY INTERFACE

The placement of the truck in the car and its relation to the beam are shown in Figure 6. The wheel rim is concave, to form a double flange for precise centering. There is a suspension linkage between truck and car with a suspension unit as shown. There is no need for the one-wheel truck to swivel in curves; this greatly simplifies the suspension.

Above each truck there is an "outrigger" that takes tension loads to prevent overturning of the car. This outrigger engages the upper rail by means of a set of rollers, four above and four below the rail's horizontal web. The rollers are mounted in a steel frame that surrounds the upper railhead; this ensures positive grip even if the rollers themselves

Figure 1. General view of Project 21 system.

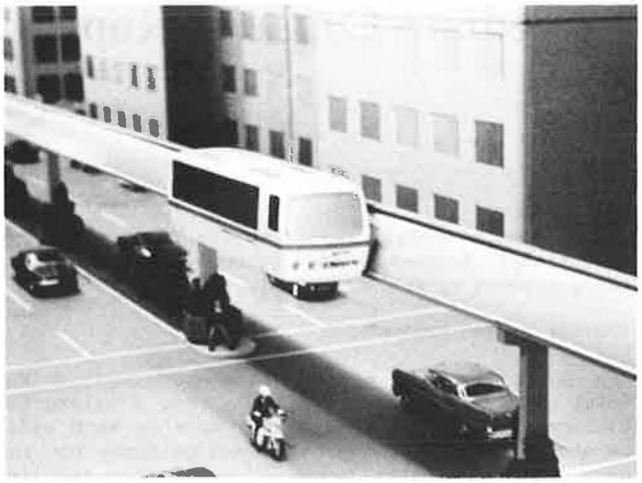


Figure 2. Cutaway view of lead car.

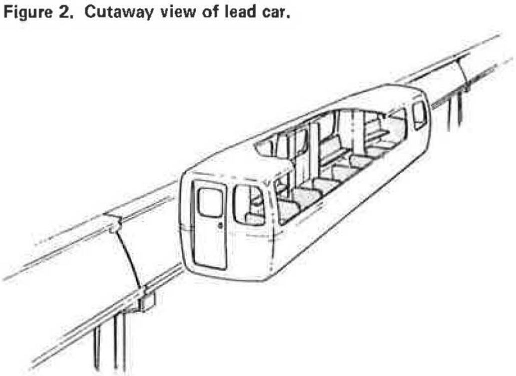


Figure 3. Floor plan of B car.

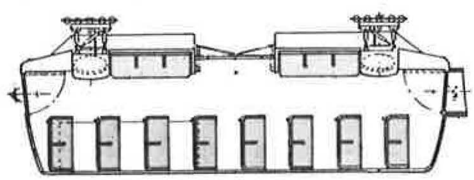


Figure 4. Inboard side of car: trucks, doors, and raised outriggers.

Figure 5. Section through car in seat area.

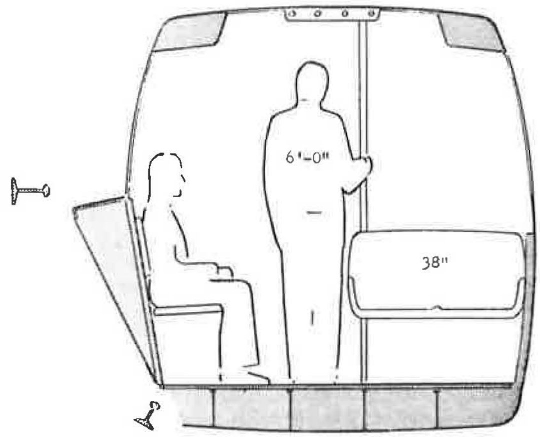
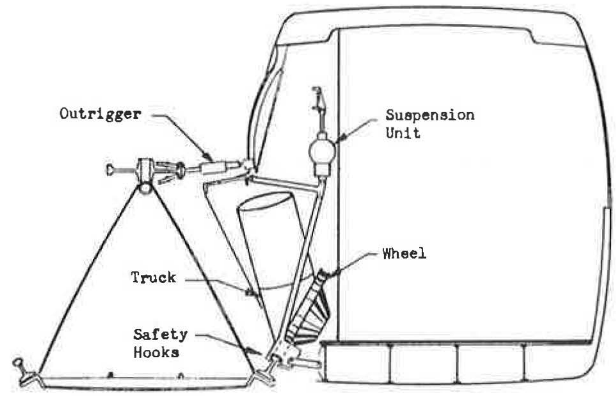


Figure 6. Section through car and beam at wheel.



should fail. The same frame also mounts the power collection shoe.

Figure 7 shows details at the apex of the beam. In addition to the two top rails and associated third rails, it shows one outrigger frame and its rollers. Also shown are the massive main power conductor, securely enclosed inside the beam structure, and a "snow guard" to protect the roller path. These details have been carefully worked out to ensure excellent all-weather reliability.

STATIONS

Stations are placed between the two tracks, which curve apart as the station is approached (see Figure 8). The waiting area is fully enclosed for environmental comfort as well as safety. The floor is level with the car, and there are generous biparting doors for access to the train. Four sets of doors on each side of the station allow trains up to four cars long.

Vertical access is by two stairways plus a large elevator, as shown in Figure 9. A 10-ft median in the street is sufficient for ground-level circulation, protective fences, and station supports.

The upper rail of the "track" alongside the station is placed above the passenger's head (Figure 9). This requires the car's outriggers to rise, at stations, to the position shown in Figure 4. The guideway transition shown in Figure 8 provides for this change in upper-rail position while keeping the cars perfectly level.

BRANCHES

The key to the Project 21 branch is a pair of back-to-back switches, each inclined to match its adjoining track. Figure 10 shows how a two-track branch line departs from a two-way trunk line. The trunk line bulges locally to blend with the switches; maximum width in this bulge is less than

Figure 7. Section at top of beam.

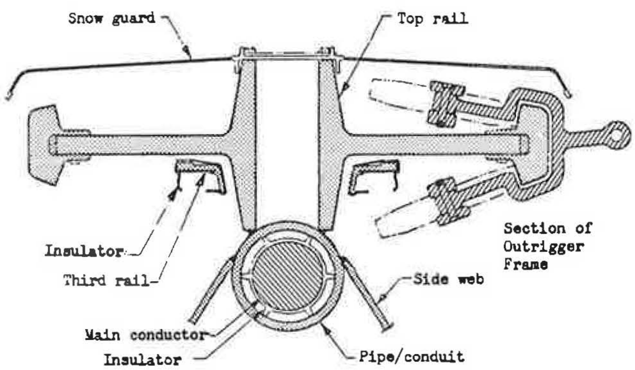


Figure 8. Basic station.

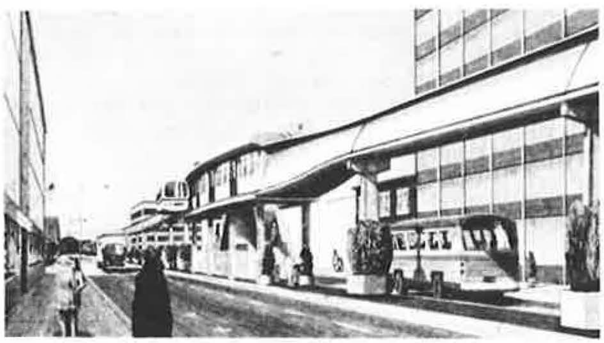


Figure 9. Sections through station at stairway and elevator.

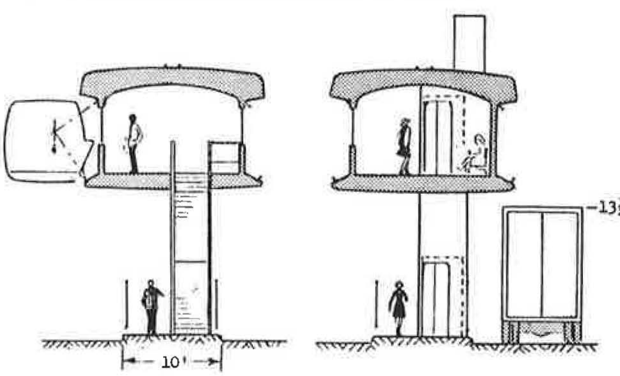


Figure 10. Branch design of 1976.

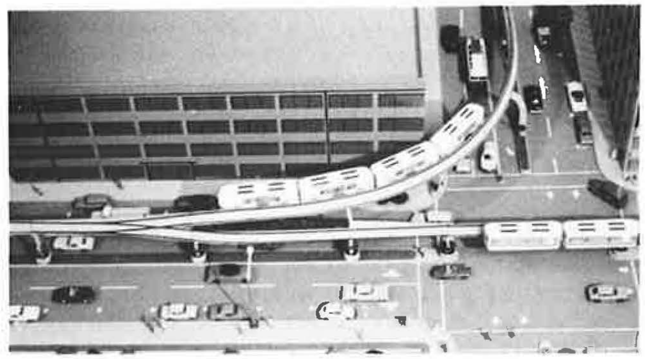
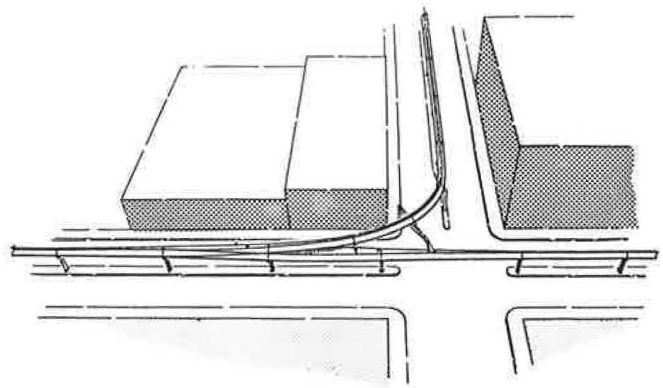


Figure 11. Computer drawing of refined branch design.



13 ft. Figure 10 shows the design as of 1976; it has since been refined for fewer columns and gentler curves, as shown in Figure 11. This allows trains to pass through at 35 miles/h on the main line.

OPERATIONS

The cars can be controlled like trolley cars, relying heavily on the operator's vision and judgment. Other control modes, including the more sophisticated Metro-type systems, can be supplied at greater expense.

Running speeds, acceleration and deceleration, and station dwell times are similar to those for today's rail rapid transit. We favor station spacing on the order of 0.33 to 0.5 mile in urbanized areas so that most passengers can walk to and from a station. Although this penalizes line-haul speed somewhat, experience in many cities teaches that it is popular with the passengers and yields high ridership. It also avoids the need for extensive feeder systems and large parking lots.

Maximum speed for the initial design is 55 miles/h, more than enough for the station spacing just discussed. Higher speeds (for airport connections and other longer-distance applications) may be available shortly after experience is gained with guideway alignment and outrigger bearing life.

Headways, governed by arrival and departure at the stations, can be as short as 50 s under operator control. On this basis, line capacity is 11 000 passengers/h/direction, matching the greatest demand of cities like Boston and Philadelphia. Off-line stations have been designed to permit express trains for longer trips. This increases system speed and efficiency; more important, it increases capacity to about 19 000 passengers/h/direction, which equals the actual ridership of all U.S. cities except New York.

The system design provides several means of emergency escape, convenient maintenance inside the hollow guideway and branch modules, and exceptional all-weather features, all of which have been reviewed with engineers in a dozen cities. Space does not permit them to be detailed here.

COST

There are indications that Project 21 will afford dramatic capital savings compared with other grade-separated transit. First, it avoids the enormous cost of tunnels. Furthermore, the guideway requires only 1200 tons of steel per mile, only one-third as much as the leading people-mover. Finally, there are the benefits of quantity production of standardized modules and minimum field work for erection and start-up.

American Bridge Division estimated the cost of the guideway at slightly more than $3 million/mile for a Project 21 network in Los Angeles. That was in 1975, and inflation would tend to increase the figure substantially. On the other hand, a number of major refinements suggested by American Bridge have now been incorporated. Today's cost may not be appreciably higher.

In comparison with other systems, the operating cost of the Project 21 system should be

1. Not as good as the few rail rapid transit systems that have one-man crews and no staff in the stations,
2. About on a par with rail rapid transit systems that have two-man crews and two to three staff persons per station, and
3. Much better than buses due to the larger train capacity (170 passengers) and considerably higher effective speed.

DEVELOPMENT

After 10 years of refinement, Project 21 is ready for the initiation of prototypes. The guideway is thoroughly designed and has been analyzed for fatigue, winds, earthquakes, and other conditions. Main details of the power distribution, car suspension, branch/switch, and station-to-guideway interface have been worked out and documented.

The contemplated development program will include quarter-scale validation mockups in the first year, half-scale running tests in two years, and first full-scale tests in three years. Commercial use at 35 miles/h should commence in four years. A regional network at 55 miles/h is attainable in five years, the time it usually takes to dig one major tunnel.

ACKNOWLEDGMENT

This is an abridgment of a 40-page professional paper that contains many more details about the Project 21 system, its rationale, and its pedigree. The full paper is available from Transit Innovations.

I am indebted to two corporations and a score of professionals whose participation and constructive criticism have been invaluable in bringing Project 21 to its present status. Among the individuals who provided assistance are the following: Sol Bucksbaum and others of American Bridge Division, U.S. Steel (guideway design, producibility, and cost); James Corl and others of Insul-8 Corporation (power distribution, third rail, and collector); Lloyd H. Donnell, American Society of Mechanical Engineers, Inc. (guideway design and analysis); and Boris Pushkarev, Regional Plan Association (the urban planner's perspective).

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

Abridgment

Organizing for Effective Rail System Planning and Implementation: The Metro-Dade Experience

CLARK P. TURNER

The transportation planning and implementation structure of Metropolitan Dade County, Florida (the Miami urbanized area), is described, and key characteristics that make it effective are discussed. Four unusual aspects of organization for effective planning and implementation of major transportation improvements combine to form a unique decision-making process. Metropolitan government permits Metro-Dade to plan and implement transportation projects and obtain local concurrences with a minimum of delay. A detailed Comprehensive Development Master Plan for staged development is unusually precise in locating major transportation improvements and has been adopted by ordinance, which gives it the force of law. The voting membership of the metropolitan planning organization (MPO) governing board is the same group of elected officials that form the Board of County Commissioners, Metro-Dade's governing body. A staff function of the county manager's office—the Office of Transportation Administration—has authority over the planning, coordination, implementation, and/or regulation of all modes of surface transportation in the county and directs the operation of public systems including Metrobus, Metrorail, the Downtown People Mover (DPM), and special transportation services. In addition, it provides the technical and professional staff for the MPO. This unique organizational structure makes it possible for Metro-Dade to build its 20.5-mile, 20-station stage 1 Metrorail system on a planning-to-opening schedule of less than 10 years and to coordinate it with all other modes. Construction of a 1.9-mile, 10-station DPM and doubling of the Metrobus fleet to 1000 vehicles will be completed to coincide with Metrorail's opening.

In 1973, Metropolitan Dade County (Metro-Dade) contracted with Kaiser Engineers to prepare a preliminary engineering study for a rail rapid transit system to serve the Miami urbanized area. By early 1975, the plan was ready for acceptance by the county, and implementation was authorized. Construction of stage 1 of the project--a 20.5-mile, 20-station heavy rail line--was initiated in 1977, and by mid-1984 the $900 million system will be operating, only nine years after plan adoption.

Complementing the new Metrorail system at its opening will be two other major transit improvements: a 10-station, 1.9-mile downtown people mover (DPM) loop connecting with Metrorail at its downtown Government Center station and a 1000-vehicle Metrobus system, double its present size, that provides express, limited, Metrorail feeder, and local services.

But the most significant achievement of all has been the creation of an institutional structure that makes it possible for Metro-Dade's transit improvement program to be carried out with maximum coordination of its three major elements while keeping delays to a minimum. Lacking this institutional structure, planning-to-opening of Metrorail and the DPM and coordination of all other surface transportation modes could not be accomplished in less than 10 years if, indeed, it could be achieved at all.

ORGANIZATIONAL STRUCTURE

Four unusual elements of organization for planning and implementation combine to form Metro-Dade's unique institutional structure: (a) metropolitan government, (b) the legal status of the Comprehensive Development Master Plan (CDMP), (c) the relation between the governing board of the metropolitan planning organization (MPO) and the general-purpose local government of the county, and (d) the Office of Transportation Administration (OTA). In brief, the unique combination of Metro-Dade's structure and operating policies works as follows.

Metropolitan Government

Dade County's "two-tier" (county-municipal) metropolitan government was created in 1957 by citizen adoption of a charter. The charter made explicit the powers of the central metropolitan government concerning traffic, transportation, and comprehensive planning. Specifically, the charter gave Metro-Dade County authority over all modes of transportation in the county, including the power to plan and operate public transportation and to regulate private transportation both in unincorporated territory and within municipal boundaries. This latter power--regulation within municipalities--is a key to Metro-Dade's coordinated planning implementation structure.

Legal Status of CDMP

Operating under the charter's provision that the county may "prepare and enforce comprehensive plans for the development of the County," the CDMP, which includes the long-range transportation plan, was adopted by the Board of County Commissioners.

Adoption of areawide comprehensive plans is by no means unusual. However, Metro-Dade's CDMP incorporates three significant features that, in combination, approach uniqueness:

1. The entire CDMP, including objectives and developmental policies, is adopted by ordinance and is, therefore, a law. It can be altered only through a detailed process of public and staff review and County Commission action.
2. The CDMP calls for staged development, limiting development to areas where services are in place or committed and restricting it in environmentally sensitive zones.
3. The Metro-Dade CDMP is prepared at a high level of detail, providing a direct guide for zoning boundaries and location of transportation facilities.

It should be emphasized again that none of these features is individually unique but their marriage in the Metro-Dade CDMP makes the plan a powerful tool for guiding metropolitan development.

Legal Status of MPO

Metro-Dade County operates under the commission-manager form of government: Legislative and policymaking authority is vested in a nine-member Board of County Commissioners, and administration is directed by a county manager appointed by the commission.

The Board of County Commissioners and the Florida Department of Transportation (DOT) agreed that the Metro-Dade MPO should develop transportation plans and programs that would "thereafter be implemented". Toward that end, the Governor of Florida designated the members of the Board of County Commissioners as the voting members of the MPO. Furthermore, staff services for the MPO are provided through an agreement with the county, a unique arrangement in which the Board of County Commissioners is also the governing board of the MPO and shares the same staff.

The OTA

In 1974, when it became clear that Metro-Dade County would be building a rapid transit system, the office of the county manager was reorganized by administrative order to include an OTA headed by a transportation coordinator. Created as a staff function to the county manager to coordinate, monitor, and evaluate the activities of line departments and agencies that have transportation planning or implementation responsibilities, OTA's authority has grown to include oversight of planning, coordination, and implementation of all multimodal transportation activities in the county. In practice, this means that OTA is cognizant of all transportation planning and implementation in the county, either directly as one of its assigned functions or as a coordinator and/or regulator of others. In addition, as mentioned earlier, OTA provides the principal staff to the MPO.

Summary

Metro-Dade has established a logical sequence of transportation planning and implementation activities, beginning with goals, objectives, and policies in a strong, comprehensive plan that in turn produces recommendations for adoption by the governing board of the MPO. The MPO board, then, acting in its capacity as the Board of County Commissioners, directs the county manager to carry out the recommendations. The county manager then directs his staff--OTA--and the recommendations are implemented through the broad powers of the metropolitan government. Within this context, "coordination" of transportation planning and implementation is not a wish--it is a given, at least to the extent that the elected commissioners and their county manager determine it to be.

KEY LEGAL AND FUNCTIONAL CHARACTERISTICS

If we use Dade County as an example, it is clear that the following provisions of its Metropolitan Charter are highly desirable for effective areawide transportation planning and implementation.

Charter Provisions

Authority must be vested in the metropolitan government to plan, implement, and/or regulate all modes of surface transportation. If the form of metropolitan government retains municipalities within it, as does Dade County's, this power must extend over them. This is an absolutely essential requirement, since it prevents a municipality from blocking a transportation improvement that requires continuity, such as a rail line. The power must be sufficiently broad, in both a legal and literal sense, to permit negotiation from a position of strength to secure local concurrence in the improvement. For example, simple authority to plan and construct a rail line through a municipality is insufficient. Urban rail systems need stations, parking garages, park-and-ride lots, feeder-bus access, and the like. Hence, local zoning regulations, building codes, off-street parking regulations, requirements for street improvements, structure heights, and dozens of other potential conflicts must be resolved through negotiation in order to effect the desired improvement. Although Metro-Dade's powers are rarely exercised to the letter, their existence is a powerful negotiating tool.

Comprehensive Plan

Authority must be vested in the metropolitan government to prepare, adopt, and enforce a comprehensive plan. Transportation facilities profoundly affect, and are affected by, all other aspects of the urban environment. It is impossible to isolate major transportation systems from any other component of comprehensive planning.

Flexibility of Organization

Authority must be vested in the metropolitan government to organize itself to plan, implement, and regulate transportation improvements in the most efficient manner. Although this requirement seems self-evident, it is startling to observe how frequently areawide metropolitan agencies overlook this fundamental point and lock themselves into an organizational structure that invites conflict and competition among various departments, agencies, authorities, and divisions.

The basic difficulty in avoiding this trap lies in the historic method of handling transportation improvements. Traditionally, one areawide agency will plan, and several others implement, according to mode and level of detail. When metropolitan agreements are created, it is too often convenient to "grandfather-in" existing agencies and authorities with the almost wistful hope that they will learn to cooperate under the new rules.

Metro-Dade's charter faced this issue squarely, even though it predated the federally mandated 3-C requirements (comprehensive, continuing, and cooperative planning). The charter calls for only four departments--finance, personnel, planning, and law--and provides for others "as may be established by administrative order of the Manager" (OTA was created by administrative order).

Summary

Whatever form the areawide "metropolitan government" agreement may take, for transportation planning, implementation, and regulation purposes, the areawide agency must be empowered to set transportation policy and carry it out, plan comprehensively for the area, and organize itself to do so efficiently and with a minimum of internal conflicts.

HOW THE STRUCTURE FACILITATES COORDINATION

Because of its mandate under the charter, Metro-Dade is the only general-purpose local government that can perform coordinative transportation functions; hence, the inherent logic in selecting as members of the MPO governing board the very same "principal elected officials" of the only local government empowered to carry out transportation improvements. In this way, the major obstacle to coordination of transportation projects--a standoff between the makers of plans and those with the power to implement--can be overcome.

This is not to say that every coordinative effort slides smoothly through the decision-making process--simply that the institutional structure greatly facilitates the process. Because Metro-Dade has authority over all transportation operations in the county, coordination of projects and operations requires only an institutional structure that forces decisions along a common path. Examples of this "internally controlled" coordination can be found in the following instances:

1. Metrobus-Metrorail interface--Bus and rail operations have been planned together, so that each mode will complement the other. A single fare will purchase a trip that makes use of any combination of these modes. Bus operations will be aimed at providing feeder service to rail as well as supplementing it. Surface street improvements, including signalization to facilitate access, are planned together with bus bays and barrier-free access at the Metrorail stations.
2. Metrorail/high-occupancy-vehicle (HOV) interface--The existing HOV (carpool and bus) lanes on Interstate 95 will be connected to a major Metrorail transfer station, parking garage, and bus bays by a flyover built with Interstate funds. This aspect of the rail project required exceptionally close coordination among the Urban Mass Transportation Administration, the Federal Highway Administration, the Florida DOT, and Metro-Dade.
3. Metrorail-DPM interface--DPM construction and operations will be closely coordinated with Metrorail. A DPM station will occupy one of the three tiers of platforms in the Government Center station in downtown Miami, facilitating transfers from Metrorail to the downtown distributor.

CONCLUSIONS

The Metropolitan Charter was adopted in 1957, the CDMP in its present broad form in 1974. The MPO was created in 1977, three years after establishment of the OTA. OTA's staff, which was one person during its first six months of existence, now numbers more than 300.

It would be presumptuous, as well as inaccurate, to contend that this unique organizational structure was created with clear, unerring foresight by the framers of the Metropolitan Charter and the CDMP. What actually happened was a creative response to the absolute necessity that the county organize for effective transportation planning and administration. Using powerful tools provided by the metropolitan charter and the CDMP, Metro-Dade created a unique and truly coordinated approach to dealing with today's urban transportation problems.

Unfortunately, metropolitan government that deals effectively with areawide issues is still in its infancy. Metro-Dade, which is among the oldest, is only 24 years old. Its experience has demonstrated that plans and policies involving transportation issues are still very volatile public concerns, no matter how convenient the institutional structure described in this paper may be. Indeed, it was citizen rejection of some 75 miles of planned urban expressways and endorsement of a 1972 bond issue that mandated Metrorail. Six years later, the same citizenry came close to wrecking by referendum the Dade County Metrorail before it could be built.

In short, institutional structures will never be able to plan and implement to everyone's satisfaction. Citizens will ultimately have the last word, and that is as it should be. Nevertheless, significant improvements can be made in our institutions to facilitate sound transportation planning. It is hoped that the Metro-Dade experience will be useful as an example of one way by which it can be done.

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

Edmonton's Light Rail Transit from Concept to Operations

J.J. BAKKER

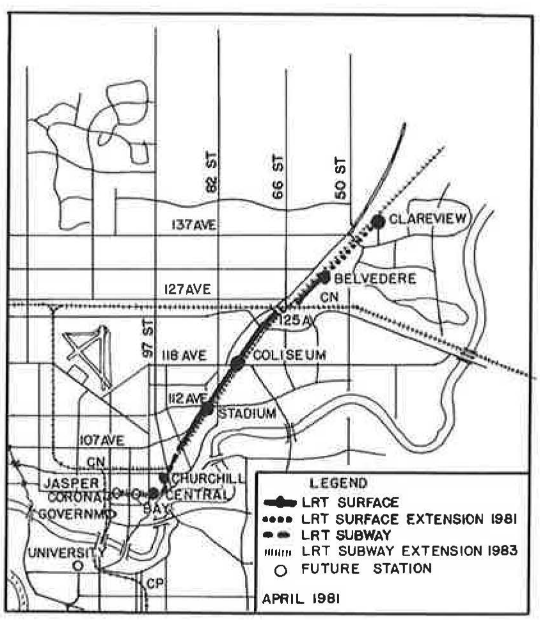
An overview of the light rail transit (LRT) operation in Edmonton, Alberta, from construction through operation, is presented. Edmonton's LRT proved to be very cost effective in the construction phase. Edmonton had few institutional constraints at the time of construction, and it also had excellent construction conditions and a small project management staff. This small staff provided oversight for the project, using consultants, architects, contractors, and other city departments to complete the work. The project managed to stay within budget and was completed ahead of schedule. Since these conditions were unique, no comparisons should be made with other cities or other countries or even with conditions as they will be in Edmonton in the future. The operating phase has so far proved to be less cost effective. The LRT operation has not produced the labor savings expected, primarily because of the fare-collection system adopted. Although there are problems in computing an operating ratio for the system because of revenue allocation formulas, it can be said that this ratio lies between 0.43 and 0.60, depending on the assumptions made. It is shown that the operating ratio will improve due to the proof-of-payment system that went into effect in November 1980. Further development in the northeast sector of the city should further improve the operating ratio in the next five years.

The Edmonton, Alberta, light rail transit (LRT) line (see Figure 1) was officially opened on April 22, 1978, ahead of schedule and within budget. It is no longer usual for public works projects to be ready ahead of schedule or to be within budget. This paper attempts to review what happened in Edmonton. There are several components that should be looked at, such as the institutional constraints, the project management, Edmonton's natural conditions, and what can be expected in the future.

INSTITUTIONAL CONSTRAINTS

In Canada, there is always some doubt as to which government is responsible--federal, provincial, or municipal. Responsibility is usually associated with the fiscal ability to finance a project. The federal government of Canada does not involve itself in any financial support for urban transit projects, nor does it support any transit system with operating subsidies. As will be described later in this paper, there was some federal involvement in the approval process for LRT in Edmonton, but the federal government was not a factor in the decision to proceed with the project.

Figure 1. Edmonton LRT line.



In Canada, the municipal governments are the creation of the provincial government. The control that the provincial government exerts is primarily by means of conditional grants and the requirement that borrowing for capital funds be approved by a provincially appointed board, the Local Authorities Board. Municipalities derive their income from property taxes, conditional and unconditional grants from the province, fees, fines, and income from municipally owned utilities.

In 1974, the provincial government of Alberta recognized that it had no experience in urban transit and that funding for transit was a desirable policy. The provincial government displayed a great trust in the cities by giving capital grants for transit that would be paid annually and were guaranteed for six years. In the case of Edmonton, this grant was \$7.5 million/year for a total of \$45 million (1). It is no coincidence that the original estimated cost of LRT in 1973 was also \$45 million. The provincial government exercised no control over the planning, design, or construction details of the project. In addition, the capital grant was paid at the start of the financial year on April 1. Any interest earned from the grant had to be spent on transit as well. At the end of each year, an accounting of the funds was required. A surplus could be carried forward and temporarily invested. In addition, an operating subsidy was provided that paid up to 50 percent of an operating deficit with a maximum per capita grant of \$3. The province of Alberta also helps municipal governments through the Alberta Municipal Finance Corporation, which is funded by the province and lends money for capital projects at an interest rate below the market rate (8 percent during the LRT construction period, when the market rate was 10-12 percent). Early in 1979, the provincial government allocated an additional \$140 million spread over six years (1979-1985) on the same unconditional basis.

There are a number of unique situations in Edmonton. The city owns the electricity, telephone, water, sewer, and transit utilities. All of these utilities except transit make a profit, part of which is used to reduce property taxes. Planning in the city is coordinated through the Municipal Planning Commission (MPC), in which the managers of the various utilities as well as city departments are represented. The city can therefore, through development agreements, keep paths open for LRT--as it did, for example, by controlling the location of piles under the Edmonton Plaza Hotel so that LRT tunnels could be bored later without interfering with the hotel foundation.

In 1974, the transit system was part of the Edmonton Transportation and Engineering Department, which was responsible for roadways, traffic operations, and transit as well as transportation planning. The transportation plan was developed by this department and became the transportation chapter of the general plan in August 1973. The first manager of the transportation planning section was D.L. MacDonald, who had been manager of the transit system and later became the manager of the LRT project.

The Edmonton City Council decided to proceed with LRT in 1973 regardless of the absence of provincial funding because of the three possible transportation solutions for the northeast area (LRT-bus integration promised the lowest annual cost to the city). The provincial grant came later in 1974, partly because the determination of the city convinced the provincial government that LRT was really needed. The provincial grant improved the least-cost alternative (2).

When construction was approved, the project manager reported to the director of transportation and engineering, who in turn reported to the commissioner of utilities and engineering (an appointed position), who reported to the City Council. The LRT project was therefore a separate section just as transit operations was a separate section. Coordination between the sections was relatively easy.

The city water and sanitation utility had extensive experience in tunneling as part of the construction of storm drains and intercept sanitary sewers. This utility was later able to act as the contractor for the tunnels between Churchill Station and Central Station. The electrical utility had already had experience with the construction and maintenance of the overhead wire system for the trolley buses. The power supply for LRT uses the same 660 V (direct current) as the trolleybuses, which allowed future savings with spare rectifiers. The electrical utility could therefore assist in the design of the LRT electrical supply system.

The traffic operations section of the department was able to integrate train control and level crossing with a computerized traffic control system (3). The result was that, after the start of LRT operations, traffic flow improved and there were fewer delays at level crossings and at intersections near these crossings (4,5).

The fact that transit was a utility did have a legal benefit as well. After the City Council approved a borrowing bylaw to finance the difference in cost between the actual cost (allowing for inflation) and the provincial government grant of late 1974, a number of citizens challenged this bylaw in court. (A bylaw in Canada is the same as an ordinance in the United States.) For public works projects, the Municipal Government Act provides that the city has to advertise the bylaw and, if 5 percent of the population signs a petition requesting a vote, a vote must be held. This procedure does not apply, however, to the extension of a utility. The city of Edmonton argued in court that the LRT project was an extension of the transit utility and that, although it used a different technology, it was not different from other extensions of the network, such as a trolleybus line or a diesel bus route. The city won its case, and the LRT project was able to proceed.

The federal government was involved in the LRT project in a number of nonfunding ways. Since the LRT operation uses a railway right-of-way for part of its length, the Canadian Transport Commission (CTC) was involved in the approval of the signal system and the at-grade crossing protection (4). The signal system used is a red and green modified block system with a clearance overlap, which is different from the standard railway signaling procedures. The level-crossing protection is integrated with the traffic signal system and again has some unique features (the system has operated safely in Europe for many years and has proved to be safe). CTC sent one investigator to study the proposals and then a second investigator, both of whom no doubt submitted reports to CTC. Then an outside consultant looked over the situation and wrote a report for CTC. Finally, approval was given. It was, of course, realized by all that refusal meant that the Commonwealth Games would not have the benefit of LRT service and that the question could therefore become a political issue.

The city signed an agreement with the Canadian National (CN) Railway to lease the rail right-of-way. CTC approved this agreement when it was discovered that such an agreement required CTC approval. The federal government also waived the requirement for most of the import duties on the LRT equipment, which came from Germany and was finished in Edmonton. There are indications that pressure from industries in Ontario may cause duties to be levied on additional LRT cars in the future. It is probably mere coincidence that an Ontario organization was importing prototype light rail vehicles for Toronto at the same time as Edmonton, but from Switzerland, and therefore also benefited from the waiving of import duties. No doubt these import duties will also be a political issue in the future.

The federal government also contributed to the 118 Avenue and Santa Rose grade separations under the grade-separation-crossing fund program. This program of assisting in grade crossings was abandoned by the federal government in 1978.

Overall, therefore, it can be said that the federal government cooperated with the city in giving the necessary approvals, contributing to funding grade separations, and waiving most import duties. This kind of intergovernmental cooperation should be normal procedure, and it is hoped that it will continue.

The city enjoys a good relationship with the engineering faculty of the University of Alberta. Faculty members have been advisors to the transit system and the rapid transit project. The faculty has taken advantage of this opportunity to initiate research projects in transportation planning, traffic management, soil mechanics, tunneling, and the structural design of tunnels. It was possible, therefore, to monitor the performance of the tunnels during construction with extensive instrumentation.

Although the institutional constraints were favorable in 1973 when the project started, changes had occurred by 1978. The provincial government now has an expanding section dealing with urban transit; however, the grants are still unconditional. At every opportunity, the city has been requesting federal involvement in urban transit. It is unlikely that the federal government will actually get involved in a time of cutbacks and restraints, but one never can tell. Under Canadian arrangements, any federal funding would be channeled through the provincial government and would no doubt require extra staff at the federal, provincial, and municipal levels. It is difficult to estimate what additional government involvement will mean in costs or time delays.

The city itself reorganized in 1977 in that transportation planning was made part of the city planning department, which reports to the city commissioner of public affairs. The transit system was made a separate department, and traffic control remained with the engineering department. The previously existing coordination within one department is now dependent on committees and the willingness within separate departments to work together or even to inform others of what is being done. Any differences of opinion or conflicts now can only be resolved at the commission-board level instead of at the department level. If conflicts are not resolved early, voluntary cooperation may suffer. An outsider does not get the impression that the process of going from planning to implementation will be speeded up by these reorganizations. It is rumored that further reorganizations will take place during 1980.

PROJECT MANAGEMENT

The Edmonton LRT project had a small management team. The manager, D.L. MacDonald, reported to the director of engineering and transportation until 1977 and then to the manager of the transit system. The other principal members of this team were R. Yacyshyn, construction manager, and W. Mitchell, who was in charge of financial control. The entire staff, including secretaries, numbered 11 persons.

The small staff allowed quick decision making. The general philosophy was to discourage or veto any proposals for costly extras but to encourage proposals that might produce reductions in project costs. Extras that were nonessential to LRT but were included in the project had to be separately funded. For example, the mezzanine floor serves as a pedway and is part of the undercover pedestrian system being developed in downtown Edmonton. The finishing of this system within the structural shell required for the LRT was funded by the pedway project. Facilities such as elevators for the aged and the handicapped also required separate funding by the City Council. An example of cost reduction was the reactivation of an old streetcar barn as the maintenance facility for LRT.

Local consultants were used from the beginning for the various project phases. The structural design used for the subway stations dictated to a large extent what could be done architecturally. Architects had to work within severe limitations and were retained on a per diem basis. Consultants were also controlled by strict budgets. Because of the small project management staff, there was very good coordination among the city, the consultants, and the architects and contractors.

The contracting philosophy was to use small, manageable contracts of about $1.5 million to $4.0 million each (1). The smaller contract size made it possible for local contractors to bid. Contractors were encouraged to produce more economical alternative designs. These designs were then evaluated by the consultants to see that they were true alternatives and indeed more economical.

All contracts were on a fixed-price basis. In a time of inflation, profits can easily disappear, particularly if there are undue delays. Many contracts were completed ahead of schedule, which in fact provided a bonus to the contractor. Progress payments were processed fast so that contractors would not be faced with excessive interim finance charges. The knowledge that progress payments were fast also meant lower bid prices on subsequent portions of the work. The small management team provided for easy communication between the construction manager and the financial manager.

Because of major construction, excavation, and tunneling in the downtown area, there is the possibility of litigation later in regard to real or imagined damage to buildings. From the outset, one consultant (independent of all other consultants) was retained to monitor the effect of construction on the surrounding environment (6). The existing condition of structures was documented prior to construction, and copies of the reports were signed by the owners of the buildings. Vertical and horizontal deformations were monitored during and after construction, and the effect of vibration and noise during construction was measured and compared with the previously measured, normal situation. The fact that building owners knew that there was an inspection report and that there was monitoring reduced the possibility of irresponsible claims. A second benefit was the public relations aspect in that the owners and tenants knew that they were being looked after. As a result of the vibration measurements, a vibratory pile-driving hammer was replaced with a diesel pile-driving hammer. Although the noise level during construction increased by about 20 dB, no litigation was initiated. With the evidence collected, it has been possible to settle the few disputes that have arisen (2).

The city was also able to do some advance buying of components, materials, or equipment. For example, the precast, prestressed concrete girders used in the downtown station construction were ordered well in advance so that the concrete manufacturing plant could schedule production during an otherwise slack period. The mole for the tunnel was purchased by the city and then made available to the successful contractor for the tunneling.

The project was constantly monitored as regards financial control. In 1974, some changes had to be made in the plans so as to reduce costs. A run-out track with a crossover switch west of Central Station was eliminated from the plans. In addition, a new maintenance facility for the LRT equipment was not built; instead, an old streetcar barn was renovated and converted for LRT use. The articulated cars made it possible to reach this facility, since the route has some sharp curves.

The cost of construction of a subway is often dependent on the number of utilities that have to be relocated as well as the soil conditions in the area. Edmonton is a young city and therefore did not have too many utilities to relocate. In addition, the soil conditions are ideal for tunneling and excavation. The water table is low and well below the subway grade. Cost comparisons with other cities are therefore not meaningful, since each city is unique.

Since the completion of the project in April 1978, the management team has been disbanded. The newly approved LRT extensions required that a new team be formed.

EQUIPMENT

In regard to equipment, the specifications stressed performance rather than detailing the car features. Because the requirements of Edmonton would not justify a specially designed model, the aim was to use the production and design developed for other customers. The second aim was to select a simple, proven vehicle.

It was also desirable to have as much local input as possible. The contract was on a fixed-price basis with Siemens Canada Ltd. for 14 cars. The price was therefore unaffected by rate-of-exchange fluctuations. The shells and trucks were made in Germany by Düwag, and the final outfitting, wiring, and interior finishing were done in Edmonton. Mechanics and electricians of Edmonton Transit were invited to apply for the job of electrical mechanic, for the task of maintaining the equipment. These men were then seconded to Siemens Canada for the assembly and finishing work in the city-owned LRT maintenance shops, where they worked under the supervision of Siemens Canada personnel. This process helped in increasing Canadian content in the cars, a factor that was used in the request for exemption from import duties.

The cooperation of the supplier and the city also provided excellent training and a thorough familiarization with the equipment for maintenance personnel. This group of people now consider themselves a selected elite and take great pride in their work. The result has been that 12 of the 14 cars can be scheduled daily for service.

OPERATING COSTS

As described earlier, the construction of the Edmon-

Table 1. Total capital costs of Edmonton LRT.

Cost Element	Cost ($)
Underground stations and subway sections	
Central Station	4 417 217
Churchill Station	9 279 782
Precast beams for Central and Churchill Stations	1 814 976
Elevators and escalators	804 300
Portal underground section	3 003 996
Underpinning	1 745 897
Properties and acquisitions	1 172 094
Utilities and relocations	3 155 468
Mined subway from Churchill to Central	2 732 601
Fire lines in underground section	100 000
Connection, Coliseum	245 000
Edmonton Telephone, telecommunications system	375 000
Total	28 846 331
Surface stations and sections	
112 Avenue Station (Stadium)	1 448 784
118 Avenue Station (Coliseum)	2 200 817
118 Avenue overpass	598 823
129 Avenue Station (Belvedere)	200 000
CN relocations	984 093
Rail transit track work and crossings	6 393 074
Santa Rosa underpass	250 000
Structure underpass under CN at 66 Street to 129 Street	2 410 300
Total	14 485 891
Electrification	3 093 702
Signaling	2 271 300
Total	5 365 002
Other	
Design and engineering	3 358 713
Maintenance yards and shops	561 000
LRT cars (14)	7 396 796
Interest during construction	1 420 796
Miscellaneous	750 000
Total	13 487 305
Total for construction and design	62 184 529
Administration	1 299 000
Advisory consultants	1 135 000
CN lease costs	130 000
Total	2 564 000
Grand Total	64 748 529

Table 2. Edmonton Transit revenue and passenger statistics.

Item	1978	1979	1980
No. of systemwide passengers	61 414 000	62 724 000	66 282 000
Systemwide revenue ($)	18 511 288	23 268 464	24 418 398
Average fare per passenger ($)	0.30	0.37	0.37
No. of LRT passengers	4 263 496[a,b]	6 255 944[b]	6 500 000[c]
LRT passengers (percentage of total)	6.9	9.9	9.8
LRT revenue from fare boxes ($)	652 162	903 569	1 026 695
LRT revenue ($)			
Based on percentage of total	1 277 279	2 303 578	2 393 003
Based on 75 percent of average fare per passenger	959 286	1 736 024	1 803 750

[a] April 22, 1978, to December 31, 1979.
[b] From counts made by fare collectors.
[c] Calculated from sample counts.

ton LRT project was in capable hands and great care was taken not to waste funds. The total capital costs of the project are given in Table 1.

The operations of the LRT system are the responsibility of Edmonton Transit. At first glance, it appears that the LRT operation has been overstaffed. The personnel consist of the following:

Category	Position	Number
Operations	Director	1
	Training supervisor	1
	Dispatcher	1
	Security supervisor (part-time to LRT)	1
	Inspector	10
	Relief inspector	3.5
	Operator	14
	Fare collector (plus two supervisors)	29
Equipment	Shop supervisor	1
	Electro-mechanic, including foreman	8
	Serviceman	7
	Cleaner	7
Plant	Supervisor	1
	Track foreman	1
	Subforeman	1
	Laborer	4
Power	Signal maintenance	2
	Overhead crew	4
Building maintenance	Janitor	12

In addition, there is a contract with a security firm to provide four men on duty 24 h/day, 7 days/week (a total of 13 guards). Since the start of operations, security has been reduced. The monitoring of closed-circuit television is now done by the central control staff.

It is expected that the maintenance personnel will be able to handle more than the initial 14 cars. A further 3 cars were ordered for the extension of the line to Clairview and were delivered in 1980. The major overstaffing occurs in the area of fare collection. It should be realized that about 60 percent of the passengers travel on passes and, of the remaining 40 percent, half will already have paid a fare on a feeder bus and use a transfer; so 31 people are employed to collect a small portion of the fares. If ticket machines were used with a proof-of-payment (POP) system, then these 31+ positions could be eliminated at a saving of $621 500/year. Several consultants and study groups have recommended this change. The Edmonton City Council approved POP on October 10, 1978. In November 1980, the POP system was instituted. The violation rate has since been about 0.26 percent of people checked (there is a $25 fine if a passenger has no proof of payment).

The costs of the transit system are operating costs only. Debenture interest, other interest, lease-back charges, and depreciation charges have been omitted. In Alberta, the provincial government gave a grant of $500 per capita in 1979 to municipalities to pay off past debts; therefore, including these charges would distort the comparison between years.

The revenue is even more difficult to estimate in an integrated system. The following assumption has therefore been made--namely, that every ride on LRT contributes 75 percent of the average fare collected on the system. It is easy to argue with this assumption, but it is based on geography and on the total distance traveled by an LRT passenger (on the average, 25 percent is on a feeder bus and 75 percent on LRT).

Table 2 gives the systemwide and LRT revenue and passenger statistics for 1978, 1979, and 1980. LRT costs for 1979 are given below:

Item	Cost ($)
7 electro-mechanics	204 640
7 LRT servicemen	128 190
7 LRT cleaners	105 610
Parts men performing for LRT	18 910
Equipment, repair, and maintenance	316 700

Item	Cost ($)
10 LRT inspectors	336 160
1 LRT dispatcher	22 760
14 LRT operators	286 230
≥29 transit fare collectors	609 905
2 transit fare supervisors	36 950
Administration	52 000
Building, station, right-of-way, signal maintenance	1 438 595
Total	3 556 650

The total transit costs for 1978-1980 are given in Table 3; Tables 4 and 5, respectively, give the recent fare history and the computation of operating ratios depending on the fare-collection method used.

In 1979 and 1980, the LRT system was as efficient in its operating ratio as the total transit system. The LRT did operate during 1979 and 10.5 months of 1980 with station attendants. Without station attendants and POP system, the operating ratios would have been substantially better than those for the rest of the transit system.

RIDERSHIP TRENDS

Ridership trends can only be measured if accurate before-and-after data are available. In this regard, there are two counting programs in Edmonton. Edmonton Transit makes counts of problem locations for operational needs and has the fare collectors count at the LRT stations. The transportation planning section has made periodic counts at a large number of locations in the city. Unfortunately, counts taken on the same day at the same location on the LRT by the different agencies vary by as much as 20 percent.

In order to measure trends on the entire transit system, I have used the counts from one agency only--the transportation planning section of Edmonton Transit. The basis here is the assumption that over the years the sign and percentage of error (if any) should be the same. Again, unfortunately, counting locations were changed before and after the initiation of LRT service, which makes comparisons difficult. The results given should therefore be viewed as preliminary. For LRT patronage, the fare collector's counts have been used.

In the northeast sector--namely, the area north of 127 Avenue (or the CN-Calder tracks) and the Beverly-Highlands area (east of the LRT track, north of 111 Avenue, south of the CN main line)--subsectioning can be used. Table 6 gives the changes in patronage over the years and illustrates the effect of LRT. It should be noted that both population and patronage in the Beverly-Highlands area decreased, although the rate of patronage increased.

It is clear from Table 6 that there is scope for a passenger increase in the northeast sector. So far, there has been little promotion, since the LRT service in the peak hours has standing room only. The city has yet to order more equipment to lengthen peak-hour trains to three cars each.

The advantage of LRT is that there is spare capacity for standees and additional patronage can be accommodated. There is, however, a need for more seated capacity in the peak hour, which would make LRT more marketable in the northeast sector. Adding an additional car would not increase operating costs significantly. The reason for constructing LRT was to be able to handle the increased peak-hour movement expected due to the development of new residential areas in the northeast sector.

The northeast quadrant is expected to grow to a population of 175 000 by 1985, or 15 percent more than in 1978. If one combines the transit trip-generation potential under current plans (26 percent versus a current 21.1 percent) and the growth of 15 percent, there is a potential market for another 8500 passengers in the northeast sector. On top of that, there is the potential of park-and-ride and land redevelopment.

CONCLUSIONS

The cost-effectiveness of LRT in Edmonton can be viewed from two viewpoints: the construction phase and the operating phase. Several factors made the Edmonton LRT project unique: There were few institu-

Table 3. Edmonton Transit revenue and expenditures.

Item	1978	1979	1980
Revenue ($)			
Cash fares			
Bus	8 643 351	9 753 851	10 487 669
LRT	652 162[a]	903 569	1 026 695
Tickets	74 938	97 691	131 505
Passes	9 145 459	12 513 353	12 772 529[b]
Total	18 506 910	23 268 464	24 418 398
Expenditures[c] ($)			
LRT	3 503 113	3 556 595	4 151 035
Other transit	39 320 887	41 591 204	51 100 349
Total	42 824 000	45 147 799	55 251 384
Operating ratio of system	0.43[d]	0.51	0.44

[a]From April 22 to December 31 only.
[b]Senior citizens travel free. Prior to 1980, compensation was paid by the Social Welfare Department. To keep revenues comparable, a charge of $0.50/senior citizen was added.
[c]Excludes depreciation and capital charges.
[d]The low operating ratio in 1978 was caused by lower fares and by higher costs due to the Commonwealth Games.

Table 4. Recent fare history of LRT.

Type	1978 1/1-3/31	1978 4/1-12/31	1979, 1/1-12/31	1980, 1/1-12/31
Adult	0.35	0.40	0.50	0.50
Child	0.15	0.25	0.25	0.25
Monthly pass	14.00	15.00	17.50	18.00

Table 5. Estimates of operating ratio for LRT.

Time Period	Fare Collection	Revenue Assumption 75 Percent of ($)	Revenue[a] ($)	Expenditures ($)	LRT Operating Ratio	Systems Operating Ratio
1978	No POP	0.37	959 286	3 503 113	0.27	0.43
	POP	0.30	959 286	3 200 000	0.30	0.43
1979	No POP	0.37	1 736 024	3 556 595	0.48	0.51
	POP	0.37	1 736 024	2 905 295	0.60	0.51
1980	No POP	0.37	1 803 750	4 151 035	0.43	0.44
	POP	0.37	1 803 750	3 383 373	0.53	0.44

[a]Passengers x 75 percent x average fare.

Table 6. Transit trip generation in northeast Edmonton.

Item	Year	Northeast Sector[a]	North of 127 Avenue[b]	Beverly-Highlands[c]
Transit passengers	1975	NA	10 313	6 360
	1976	25 499	11 313	6 014
	1977	28 292	13 688	7 028
	1978	31 942	17 415	6 923
Population	1975	139 985	66 003	27 905
	1976	143 135	74 037	27 147
	1977	150 218	81 042	27 202
	1978	151 529	84 791	26 525
Trips generated as percentage of population	1975		15.6	22.8
	1976	17.8	16.2	22.2
	1977	18.8	16.9	25.8
	1978	21.1	20.5	26.1

Note: All passenger counts are based on data from the transportation planning section of Edmonton Transit.
[a]East of 97 Street and north of the North Saskatchewan River.
[b]East of 97 Street and north of 127 Avenue.
[c]East of LRT, north of the river, south of the CN tracks.

tional constraints, and that there were favorable construction conditions. Any comparisons, therefore, should take these unique factors into account, since it may not be possible to duplicate these conditions again, not even in Edmonton.

The operating phase shows that the promised labor saving from LRT was not realized initially in Edmonton. The main reason for this lack of productivity is the type of fare collection adopted. With the adoption of the POP system, the operating ratio for LRT should improve in the coming years in comparison with the remainder of the transit system.

The real value of the LRT system will not show until the new areas in the northeast sector have been fully developed and the trains have been lengthened. Although costs are expected to increase because of the lengthening of the line, revenue should also increase. The prospect, therefore, is that the operating ratio will improve for LRT whereas that of an all-bus system cannot improve at the same fare levels.

ACKNOWLEDGMENT

I gratefully acknowledge the data made available to me by Edmonton Transit. The interpretations and conclusions drawn from them are my own.

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

Abridgment

Management Decision Model for Light Rail Vehicle Service: Development and Application

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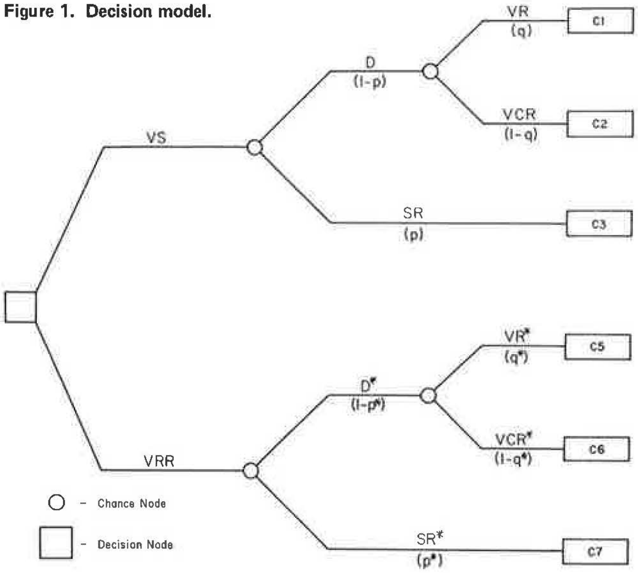
A vehicle reliability methodology to aid in the determination of an operating service policy or maintenance schedule for a light rail transit system is presented. A decision-theoretic approach is developed to balance the costs of troubleshooting and regular maintenance against the risks of breakdown, repair, and passenger delay. The reliability of a vehicle is compared with a critical vehicle reliability obtained from the decision-theoretic approach to determine the suitability of a vehicle for service or to determine the optimal scheduling of the next regular maintenance to minimize expected cost. This expected cost includes the cost of passenger delay in addition to operating and maintenance costs. To provide an example of how the methodology is used, reliability distributions were fitted to the miles between discrepancies for the propulsion, electrical, brake, and door subsystems based on data from the Massachusetts Bay Transportation Authority. Flexibility in applying the technique is illustrated in a sensitivity analysis. Changes in the decision process are shown with respect to changes in five key parameters.

Vehicle procurements throughout the past decade have brought about dramatic changes in the design and complexity of rail transit vehicles. Increased complexity, however, often causes total equipment reliability to decrease (1, p. 5).

The American Public Transit Association (APTA) has been developing a program that identifies the scope and estimated acquisition and maintenance costs of information and data, including hardware components critical to system availability and dependability. Problems with maintenance scheduling and fleet availability have also resulted from equipment complexity. The application of reliability techniques has evolved to reduce the escalating costs of maintenance; to assist in this regard, the federal government has recently begun to collect and organize vehicle failure data through the Transit Reliability Information Program (TRIP) (2). Within specific systems, reliability assessment of the Bay Area Rapid Transit (BART) system includes "analyzing the slope of the failure rate trend, following preventative maintenance, to be used as a guide for

Figure 1. Decision model.



evaluating the proper period between planned maintenance actions" (3). The Research and Development Division of the Ontario Ministry of Transportation and Communications computes the mean miles between defects, miles between defects, and an appropriate probability density function of the miles between defects for various vehicle types (4, p. 1).

A decision framework is proposed in this paper to determine whether a light rail transit (LRT) vehicle is sufficiently reliable to place into revenue service. The model can also be used to determine the optimal period until the next regular maintenance should be scheduled.

Two key terms are defined in APTA's glossary of reliability terminology (5). A discrepancy is a nonconformance of equipment or nonequipment items to stated standards exclusive of the external environment. A service failure not only prevents the unit from performing its intended function but also disrupts or delays scheduled service.

METHODOLOGY

Decision Framework

Consider first the immediate decision to approve or not to approve a vehicle for revenue service. Figure 1 summarizes the alternative decisions and possible outcomes. It is assumed that an operating manager may choose to place the vehicle into service (VS) or remove that original vehicle and replace it by a backup vehicle (VRR). In either case, the vehicle in service either suffers a discrepancy (D or D*) or completes the run with no discrepancy (SR or SR*). If a discrepancy occurs, depending on its nature, either the operating vehicle is able to complete the run and is then repaired (VCR or VDR*) or it must be removed from service immediately. C1 through C7 represent the costs associated with the various combinations of events. It is important to note that some of the costs must include the cost of passenger delay. p and p* represent the reliabilities (i.e., probabilities that no discrepancy occurs) for the original and backup vehicles, respectively. q and q* represent the proportions of vehicles suffering discrepancies that must be removed from service (i.e., the conditional probabilities of a discrepancy being serious enough to require immediate removal of the vehicle from service).

The operating manager must choose VS or VRR and will encounter one of the costs C1 through C7 based on a combination of the probabilities p, p*, q, and q*. Assuming that all costs, including passenger delay, can be measured in dollars, it is reasonable to choose the option that results in the minimum expected cost. For the decisions VS and VRR, the expected costs, EC(VS) and EC(VRR), can be written as

$$EC(VS) = (1 - p)[(q)C1 + (1 - q)C2] + (p)C3 \quad (1)$$

$$EC(VRR) = (1 - p^*)[(q^*)C5 + (1 - q^*)C6] + p^*C7 \quad (2)$$

Thus, if EC(VS) is less than EC(VRR), the vehicle should be put into service. If EC(VS) is greater than EC(VRR), the original should receive maintenance and the backup vehicle should be put into service.

Alternatively, we could determine that value of the vehicle reliability p, at which EC(VS) = EC(VRR) or at which the manager is indifferent between placing the original vehicle into service or removing it. This critical value of p is denoted p_{cr}. Decisions will be made as follows. If the vehicle reliability p is greater than p_{cr}, the original vehicle should be placed into service. If p is less than p_{cr}, the original vehicle should receive service and the backup vehicle should be used.

Setting the two expected costs equal and solving for p,

$$P_{cr} = \{[(q)C1 + (1 - q)C2] - (1 - p^*)[(q^*)C5 + (1 - q^*)C6] + p^*C7\} \div \{[(q)C1 + (1 - q)C2] - (p)C3\} \quad (3)$$

This framework can also be used for scheduling regular maintenance if the vehicle reliability is a function of the vehicle mileage.

Vehicle Reliability

A vehicle can be modeled as a set of interacting subsystems. If it is assumed that discrepancies occur independently within subsystems, then the vehicle reliability p becomes the product of the subsystem reliabilities. If stochastic independence is not appropriate, then other models can be used, leading to more complicated functions.

By using available data on some indicator of vehicle use such as miles between discrepancies (MBD) and an appropriate failure-rate distribution, the reliability of each subsystem can be written as a function of, say, MBD.

When one knows the number of miles since the last discrepancy for each system, one can determine each subsystem reliability and therefore the vehicle reliability. Alternatively, knowing p_{cr} and using the inverse process, one can determine the number of miles that the vehicle has yet to travel until its reliability is reduced to p_{cr}. Regular maintenance can be scheduled for the time when this number of miles will be accumulated.

FORMULATION OF SERVICE POLICY

Basic Assumptions

The methodology previously described is applied to an LRT line modeled on a section of the Massachusetts Bay Transportation Authority (MBTA) Riverside Line. A profile of the line's operating characteristics during a workday morning peak period included stations, distances, travel times, boardings, and alightings along the route.

Based on available data and average costs for maintenance of way, maintenance of equipment, power, the conducting of transportation and administration, and miscellaneous, a total cost of \$7.32/mile (in

1979 dollars) was estimated. Furthermore, passenger time was assumed to be worth $4.00/h, the diagnosis of a discrepancy was estimated to be $9.01, and an unscheduled maintenance action was $77.25/action on the average. For this example, C1--assumed to include the cost of a run, expected passenger delay time, and an unscheduled maintenance action--was estimated at $286.28. Expected passenger delay was calculated by using probabilities proportional to distance between stations. It was further assumed that delayed passengers would wait 7 min (the headway) until the next regularly scheduled vehicle arrived. C2, estimated to be $143.03, was assumed to include the cost of a run and an unscheduled maintenance action. C5, C6, and C7 were assumed to be equal to C1, C2, and C3, respectively, plus the cost of diagnosis ($9.01 for the original vehicle in each case).

The data also indicated that about 50 percent of all discrepancies required the vehicle to be removed from service. Hence, q was taken as 0.5. The reliability of the replacement vehicle, p*, was assumed to be 0.70.

Decision Rule

By using the data, the basic assumptions noted previously, and Equation 3, p_{cr} was calculated to be 0.22. Although this may seem to indicate a very unreliable vehicle, note that there is a 61 percent chance that no passengers will be delayed, since 50 percent of the vehicles that develop an equipment discrepancy can still complete the run.

Assessment of Vehicle Reliability

MBTA vehicle 3400 was chosen for this example. The vehicle was modeled as the independent interaction of four subsystems: propulsion, electrical, brakes, and doors. For each subsystem, the probability of a discrepancy was modeled as a function of the MBD by using a two-parameter Weibull distribution and fit by the method of moments (6, p. 40). A chi-square test was used to check acceptable goodness of fit. The Weibull distribution was chosen because of its common use in failure-rate analysis and its general flexibility of shape. In this form, each subsystem reliability was calculated as $\exp[-(\text{MBD}/\theta)^{\beta}]$.

Decision

Each subsystem reliability was estimated, and this resulted in a vehicle reliability of 0.84. The data for this estimate are as follows:

Subsystem	θ	β	Miles Since Last Discrepancy	Reliability
Doors	6756	0.83	200	0.95
Electrical	7740	0.89	150	0.96
Propulsion	7463	0.83	300	0.97
Brakes	9571	0.94	180	0.95

Since the reliability is greater than p_{cr} = 0.22, the vehicle should be approved for service.

Alternatively, by using the same models and data, it can be shown that the reliability of vehicle 3400 would be reduced to 0.22 after it has been in service for another 2300 miles. Thus, regular maintenance should be scheduled when the vehicle is expected to achieve this mileage.

Sensitivity of Parameters

The decision rule was formulated as a basis for illustrating the concepts used. Some key parameters assumed in this base problem are likely to be different in actual operations. A sensitivity analysis was performed in order to assess the effects of changes in five parameters (proportion of in-service discrepancies, reliability of replacement vehicle, value of passenger travel times, number of delayed passengers, and peak-period headways) on the critical value of p.

CONCLUSIONS

A framework has been presented for determining a service policy that combines several aspects of transit operation usually considered independently. A decision model is developed that is intended to minimize the long-run operating costs of an LRT system. Of key consideration to the process is the light rail vehicle and how well it can be expected to perform. Vehicles are put into revenue service, or regular maintenance is scheduled contingent on an expectation of realizing a minimum expected cost, which includes the cost of passenger delay.

To make this framework operational for any LRT system, the model must be structured carefully. Do other decision options exist for the operating manager? Are the estimated costs sufficiently accurate? Is the model consisting of independent subsystems realistic? Is the Weibull distribution appropriate, and what other distributions may be more suitable under specific circumstances? Is it realistic to assume that, in the event of a service failure, passengers will be delayed an amount of time equal to the headway? Are subsystem reliabilities functionally dependent on MBD only?

ACKNOWLEDGMENT

We wish to acknowledge the gracious assistance of Mary Roos, Louis Frasco, and Richard Robichaud of the U.S. Department of Transportation (DOT) during the development of this work, the MBTA for providing data, and DOT and Northeastern University for providing computation facilities and time. However, the ideas and their implementation and the conclusions of this work remain solely our own responsibility.

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

Second-Generation UMTA Transit Station Simulation Model

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The Transportation Systems Center, under the sponsorship of the Urban Mass Transportation Administration, is developing a second-generation transit station simulation model called USS II. This new discrete-event simulation program will offer significant improvements over its predecessor, USS I, in terms of ease of use, station modeling capabilities, and simulation accuracy. The major features of the current USS II design with respect to its modeling capabilities, outputs, and operational environment are described.

During the latter half of the 1970s, the Urban Mass Transportation Administration (UMTA) developed a transit station simulation model called USS (1). USS is a discrete-event, Monte Carlo type of computer simulation program designed as a tool to aid transit planners, engineers, and architects in the evaluation of alternative transit station designs. The model permits a user to define the structure of a station (e.g., entrance and exit points, processing devices, and loading platforms) and operational attributes (e.g., distributions of pedestrian and vehicle arrivals at the station), simulates the operation of the station, and produces output statistics that describe the performance of the station (e.g., queuing and congestion levels).

Using the USS program, a designer may test a broad range of potential station configurations in a relatively short period of time, thereby assisting in the development of a cost-effective station design that meets or surpasses user-established station performance standards. Thus, use of the USS model can potentially result in major cost savings for transit system construction by more accurately predicting space and equipment requirements for transit stations and reducing "overdesign" of station components. Moreover, use of the model can result in safer and more convenient station designs by highlighting sources of pedestrian delay and flow conflicts and by measuring performance under emergency evacuation conditions.

Experience with USS has shown that, although it is a basically useful station design and evaluation tool, the program has some serious deficiencies (2-4). These include the inability of the program to adequately model some existing stations, excessive requirements for user sophistication and effort, and several conceptual inadequacies in the modeling of pedestrian movements. In addition, the program has proved to be very difficult to upgrade. Because of these shortcomings, the USS program has been distributed to only a handful of users, primarily for testing purposes.

Work is now under way on a replacement for USS. This new station simulation program, USS II, is intended to be a major improvement over its predecessor (now called USS I), particularly in terms of easier model operation (i.e., greater user orientation), increased modeling flexibility and accuracy, and improved program maintainability.

It should be understood that USS II does not yet exist in executable form; only the fundamental design work has been completed. This paper describes the major features of that fundamental design. By publicizing USS II at this time, before actual programming begins, it is hoped that interest among potential future users will be stimulated and that the discussions resulting from this paper will ultimately improve the quality of the final software product.

In comparison with USS I, USS II incorporates major technical improvements that make it a more powerful analysis tool as well as a number of environmental improvements that make it easier to use and maintain. The remainder of this paper describes the major technical and environmental features of USS II as currently designed.

MODELING CAPABILITIES

Pedestrians

Pedestrians using the station are stratified by pedestrian type. Each modeled pedestrian is described by a crush area (the area occupied by the pedestrian under extremely congested conditions) and a free walking speed (the velocity at which the pedestrian will move if unimpeded by congestion). Each pedestrian also has an origin and a destination.

The set of pedestrian types is constructed by taking all possible combinations of values of a user-defined set of discrete stratification variables. For example, if the possession of a prepaid pass and a pedestrian's handicapped status are the two determinants of the pedestrian's behavior in the station, then the user would define two discrete stratification variables, each having two possible values.

These two stratification variables imply the existence of four pedestrian types:

1. No handicap, no pass;
2. No handicap, pass;
3. Handicapped, no pass; and
4. Handicapped, pass.

USS allows the user to define any number of stratification variables and as many as 99 values in each variable. Consequently, the number of different pedestrian types that can be defined in USS II is theoretically unlimited.

The pedestrian's crush area is modeled as a function of the pedestrian's type and is fixed for all pedestrians of the same type.

The free walking speed is a function of the pedestrian's type and is randomly drawn at the time the pedestrian enters the station from a user-defined distribution of walking speeds for pedestrians of that type.

The pedestrian's origin and destination are also determined at the time the pedestrian enters the station and depend on the structure of the station and the transit service associated with the station. Origins and destinations are discussed further later in this paper.

The set of pedestrian types is fixed for the duration of the simulation, but the attributes of each pedestrian type--the crush area and the distribution of free walking speeds--can be changed by the user as the simulation proceeds.

Transit Service

The transit service associated with a station is represented as a set of routes, where each route simply represents a distinct set of unspecified external origins and/or destinations. This definition is sufficiently general to permit routes to represent both scheduled and unscheduled transit service.

Each route has a mean service frequency (i.e., the expected number of arrivals per hour), a train size (i.e., the number of vehicles per arrival), and a vehicle type. These route attributes can change as the simulation proceeds, but at any point in time are fixed for each route.

Each vehicle has, for each of its two sides, a doorway capacity (i.e., the number of pedestrians that can simultaneously enter or leave the vehicle) and a distribution of doorway service times. In addition, the vehicle has an area or capacity. All of these vehicle attributes are fixed for the duration of the simulation.

Any number of routes and vehicles may be defined in USS II. The set of routes serving the station is fixed for the duration of the simulation, but the route attributes may vary. In short, USS II, through the route and vehicle entities, affords the user considerable flexibility in the specification of transit service.

Station Structure

A station model should be capable of representing virtually all physical station attributes that influence pedestrian movement through a station. This is accomplished in USS II through the use of two basic modeling entities: sectors and nodes.

Station sectors are used to represent discrete pedestrian flow areas such as lobbies, corridors, stairs, escalators, elevators, ramps, and platforms (i.e., passenger boarding and deboarding areas). A station consists of one or more contiguous sectors. Sectors usually (but not always) represent areas separated by physical barriers and/or service devices or doorways. Besides a type and a shape, each sector also has an area or capacity and either a speed (if the sector is an escalator or elevator) or a volume-delay function that governs the speed at which pedestrians move through it. The list of pedestrian exclusions and the speed and volume-delay functions may vary as the simulation proceeds, but the type, shape, and area of each sector are fixed.

Nodes are used primarily to represent passenger processing entities such as service devices (e.g., turnstiles and pass gates), doorways (including entrances and exits), diversion points (e.g., newsstands, rest areas, and ticket vendors), and transit boarding and deboarding points. Each node may have delays associated with it (i.e., service times, opposing flow delays, etc.), and thus queues may form at the node. In addition, each node may be assigned restrictions pertaining to directionality (i.e., one-way or two-way flow), capacity (i.e., the number of pedestrians that can be processed simultaneously), and allowable pedestrian types (e.g., modeled wheelchair patrons may be prevented from using escalators). With the exception of directionality, all node attributes can vary during the course of the simulation.

Each node must appear on the boundary of two and only two sectors (since the "outside" is regarded as a sector, nodes may be positioned on the exterior boundary of the station and still meet this condition). USS II automatically connects each pair of nodes on the boundary of each sector in each allowable direction with a link. This node-link network represents all possible pedestrian-movement paths within the station.

The important element to note is that links are not specified by the user; they are automatically generated by USS II from user-supplied node and sector information. This feature greatly reduces the user input requirements for USS II in comparison with USS I.

Pedestrian-Transit Interface

Accurate modeling of pedestrian behavior with respect to the transit service in the station was one of the highest USS II design priorities. It is accomplished through the use of waiting rooms, platforms, dock nodes, docks, and tracks.

A waiting room is a sector in which transit-bound pedestrians may wait for the arrival of trains. Each waiting room may serve as few as one or as many as all transit routes, the set of routes served being defined by the user.

A platform is a waiting room at which vehicles can dock. Part of each platform's perimeter must be on the station perimeter, and that part of the perimeter must have at least one node, called a dock node. A dock is an ordered set of dock nodes located on the perimeter of a common platform. A track is an ordered set of docks that may or may not be on the same platform. Figure 1 illustrates these concepts.

The user must provide, for each route, a prioritized list of docks that identifies the set of docking locations available to trains on that route. Every list must contain at least one dock, and each dock in a route's list must contain at least as many nodes as there are cars in a train on that route.

The waiting room-route and platform-dock relations are fixed for the duration of the simulation, but a route's list of prioritized docks may change as the simulation proceeds.

Demand

Demand for the use of the station is modeled in USS II as a set of origin-destination demand tables, one table per pedestrian type. Each demand-table cell contains the arrival rate (pedestrians per hour) for a particular pedestrian type from a particular origin to a particular destination. The demand tables can be changed during the course of the simulation, thus permitting the user to model varying demand levels and mixes of pedestrian types over the duration of the simulation.

The set of origins is composed of the set of entrance nodes plus the set of routes serving the station. The set of destinations is composed of the set of exit nodes plus the set of routes serving the station plus the set of route groups, if any. A route group is a set of two or more routes that provides joint service to some external destinations; all routes in a route group are regarded jointly as a station destination by any pedestrians headed for one of those external destinations. The structure of the demand tables is shown in Figure 2.

Pedestrian arrivals at entrance nodes are generated randomly by using a user-specified distribution around the average; the average arrival rates are provided by the demand tables. Arrivals are generated independently for each cell in the demand tables, so at generation time the pedestrian type, origin, and destination of each generated pedestrian are known.

Pedestrian arrivals by transit are generated similarly but appear as a group when a train arrives on a route. The number of persons on board a train is derived from the pedestrian arrival rate for the route (i.e., the sum of the arrival rates for all demand cells that have that route as an origin), the expected train frequency on the route, and a user-specified distribution of variations from the mean. The number of arrivals that do not deboard is known

Figure 1. Basic modeling concepts.

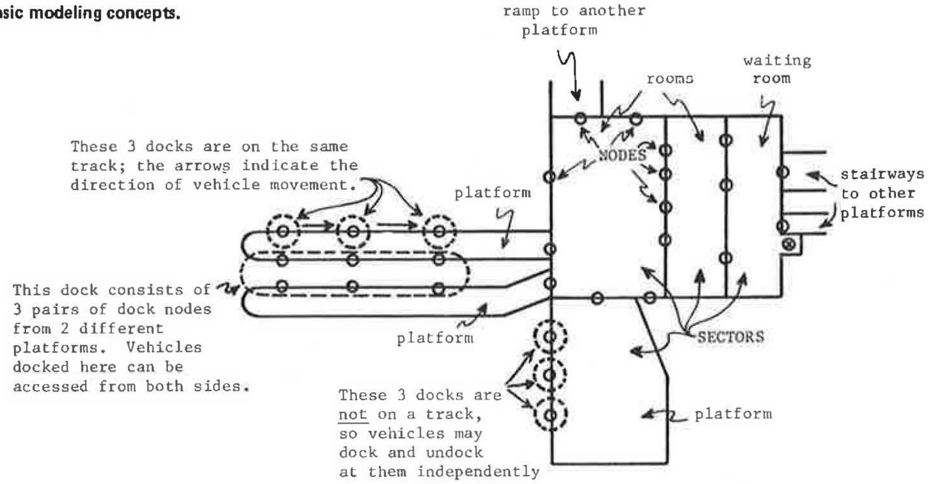
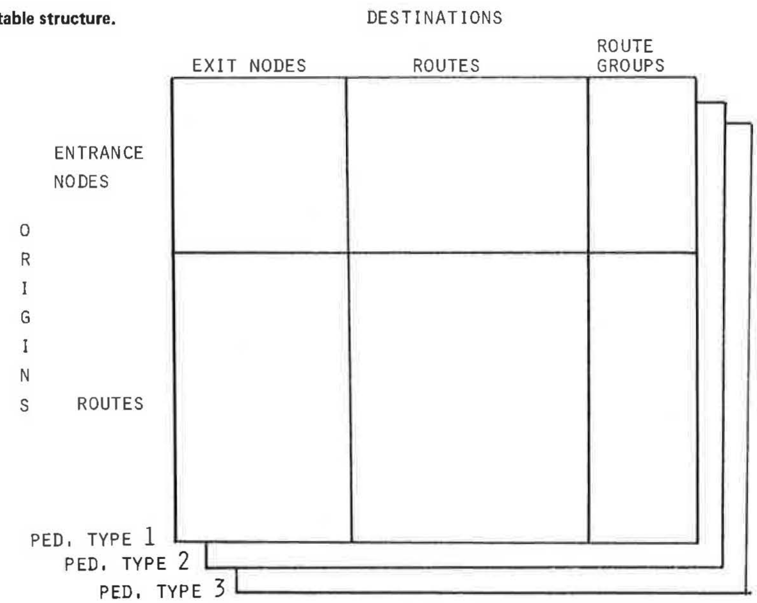


Figure 2. Demand-table structure.



from the demand cells that have that route as both an origin and a destination. The remaining pedestrians deboard when the train docks and thereafter move through the station in the same way as pedestrians who arrive on foot.

Pedestrian and Train Movements

The movement of pedestrians through the station can be modeled at a potentially high level of detail in USS II. Pedestrian routing from arrival to departure through the station's link-node network is accomplished by using a dynamic multipath assignment procedure. According to this procedure, each pedestrian probabilistically "chooses" a path from present location to destination (i.e., his or her transit route or station exit) based on the relative travel times by those paths. The total travel time is a composite of walking and conveyance time, service time, time in queues (waiting for service), and, if the destination is a transit route, time spent waiting for a vehicle. A pedestrian updates his or her path choice each time he or she enters a new sector.

Numerous options are provided for controlling pedestrian movements. One important feature allows the user to define horizons (or groups of station sectors) within which pedestrians possess "current" information on travel conditions. Beyond the bounds of his or her horizon, a pedestrian knows only the "expected" travel conditions. This feature is important when the user wishes to accurately model situations in which pedestrians have clear lines of sight (or can otherwise perceive operations) over a large area of the station. Both expected and current times can be generated automatically by USS II without input from the user.

Another important pedestrian-movement feature provided by USS II is the ability to model the use of intermediate destinations, or diversions. The use of a diversion--a newsstand, a change booth, or a ticket vending machine, for example--is modeled as a Markov process in which the probabilities of use are supplied in diversion tables stratified by pedestrian type, much like the demand tables. Like demand tables, the diversion tables may change during the course of the simulation.

Capacity constraints are incorporated into the USS II movement algorithms in two ways:

1. A sector may become full (i.e., the sum of the areas of the pedestrians in the sector may ex-

ceed the sector area). If this occurs, pedestrians are prevented from entering the sector until space becomes available; pedestrians waiting to enter the sector queue up at the nodes on the sector boundary.

2. A node may become full (i.e., the number of pedestrians being served may equal the node capacity). If this occurs, pedestrians are prevented from entering the node until a pedestrian leaves the node. These two types of capacity may be viewed as "volume capacity" and "flow capacity".

Additional pedestrian-movement features of USS II include the ability to model different types of pedestrian queues (first in/first out and random) and the ability to model different policies for resolving directional conflicts at a node. USS II also provides an "evacuation" mode of operation that automatically changes the station's operating characteristics to simulate a crisis. In this mode, pedestrian and train arrivals are terminated, trains in the station are unloaded, pedestrians are rerouted to exits, and their walk speeds are increased.

With respect to the movement of trains, USS II stops short of explicitly tracking their movement within the station; only when a train is docked is the exact position of the train known. However, the user can model most of those aspects of train movement that affect the operation of the station. For example, a dock may be allocated to a train for a period longer than the actual docking period; this feature may be used to simulate the effect of control signal blocks, for example. Similarly, serial dependence of one dock on another (as when two docks are on the same track) can be modeled.

When a train enters the station, its route's list of docks is searched for an available dock and, if any are available, the train is allocated to ("docked at") the dock that has the highest priority. If no dock in the list is available, the train waits until one becomes available. This mechanism allows the user to model dynamic dock-allocation policies.

When a train docks, all pedestrians waiting for it (i.e., waiting for an arrival on this route or on a route group that contains this route) on all platforms and in all waiting rooms associated with the route are released and move toward the train. Those pedestrians waiting for the train on the platform at which it docks instantaneously queue up at the individual vehicles of the train--i.e., at the dock nodes corresponding to the vehicles (there is a one-to-one correspondence between dock nodes and docked vehicles). As pedestrians arrive at this platform from other locations, they are subjected to a fixed delay (representing the minimum platform traversal time) and then are instantaneously transported to the docked vehicle doorways.

When the doors of the vehicles open, all deboarding passengers leave and boarding passengers enter. If the train reaches capacity before all queued pedestrians have boarded, or if the doors close before all have boarded, then all remaining pedestrians wait on the platform for the next arrival. If one car becomes full before the others, pedestrians queued at the full car automatically requeue at the other cars.

Once its doors are closed, the train attempts to leave the station. However, it may be prevented from doing so by another train in front of it on the track (if the dock is on a track). If so, the train waits until its way is clear and then departs. The dock is unavailable for use by a second train until the first one leaves the station.

MAJOR ENVIRONMENTAL FEATURES

Providing adequate station modeling capabilities was an important USS II design goal. Equally important, however, was the goal to make USS II directly usable by architects, planners, and others who have little or no computer expertise. Meeting this goal required the development of a "friendly" user environment. This section describes the major environmental features of USS II that make it a very friendly program.

User-Control Interface

The USS II user-control interface is designed to operate primarily in "interactive" mode, which means that the user can input control information as the program is executing. However, USS II can also operate in the cheaper "batch" mode to reduce the cost of operation.

The current design of the USS II user-control interface requires the use of a Tektronix 4014 storage-type cathode ray tube (CRT) display terminal. The bulk of the user inputs are designed to be provided graphically--which means that a CRT terminal is required--and the Tektronix was selected because it is one of the most widely available. However, a goal of the detailed design effort is the elimination of this Tektronix dependence.

The USS II user-control interface is completely passive; that is, all of the USS II control information is provided in response to prompts and menus and the user does not have to learn a USS II "command language". Moreover, the USS II user has access to "on-line" assistance in responding to any prompt or menu. In short, the USS II user-control interface is interactive, passive, and self-documenting.

Data Base Management System

The information needed to adequately simulate the operation of a transit station is necessarily complex and voluminous. Moreover, the information produced by such a simulation is also of necessity complex and even more voluminous. The organization, management, and manipulation of these vast quantities of input and output data are difficult tasks that, left to the user, would overwhelm him or her and make USS II unusable. It was imperative that, as part of USS II, comprehensive automatic data storage and retrieval capabilities be provided. In short, one of the USS II design goals was to provide a data base management system (DBMS).

The basic structure of the data to be stored in the DBMS is shown in Figure 3. The core of the data base--the data relating to stations--is hierarchical in structure. Each station can have several versions (i.e., several structural variations), each version can be simulated several times by using different control parameters and transit services, and each simulation consists of one or more time segments (i.e., one or more periods in which all operating parameters are fixed). Demand tables (i.e., pedestrian origins and destinations) are associated with a station at the simulation level but are used at the time-segment level, as is all information related to transit service. Pedestrian characteristics are related to the station at the simulation level, but pedestrian restrictions (e.g., the exclusion of cash-paying customers from prepaid pass gates) are established at the time-segment level.

In this data structure, the transit service information is largely independent of the station information. This arrangement permits the modeling of transit service independent of station design. An important implication of this independence is that a network of transit service, once modeled, may be used with little or no additional effort in the

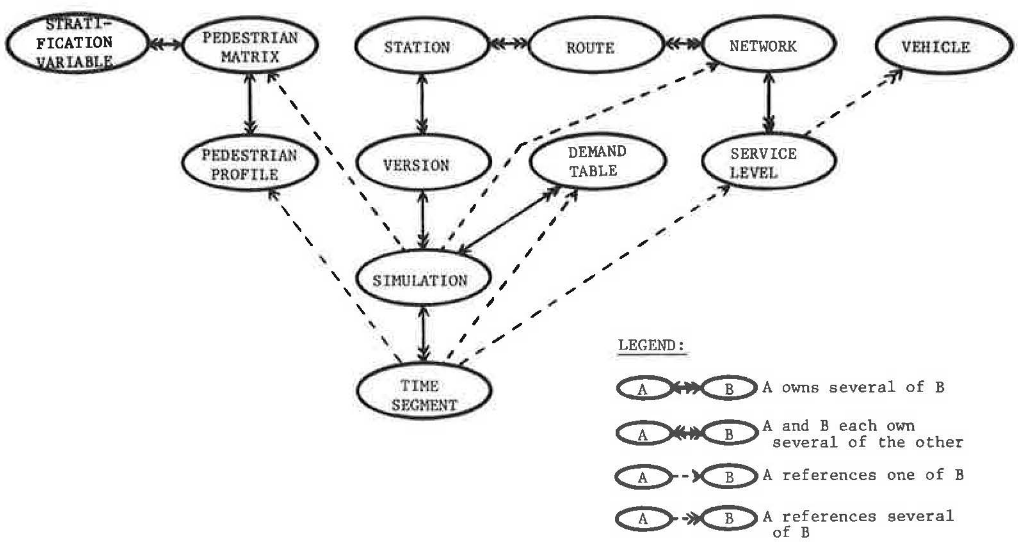


Figure 3. Basic USS II data structure.

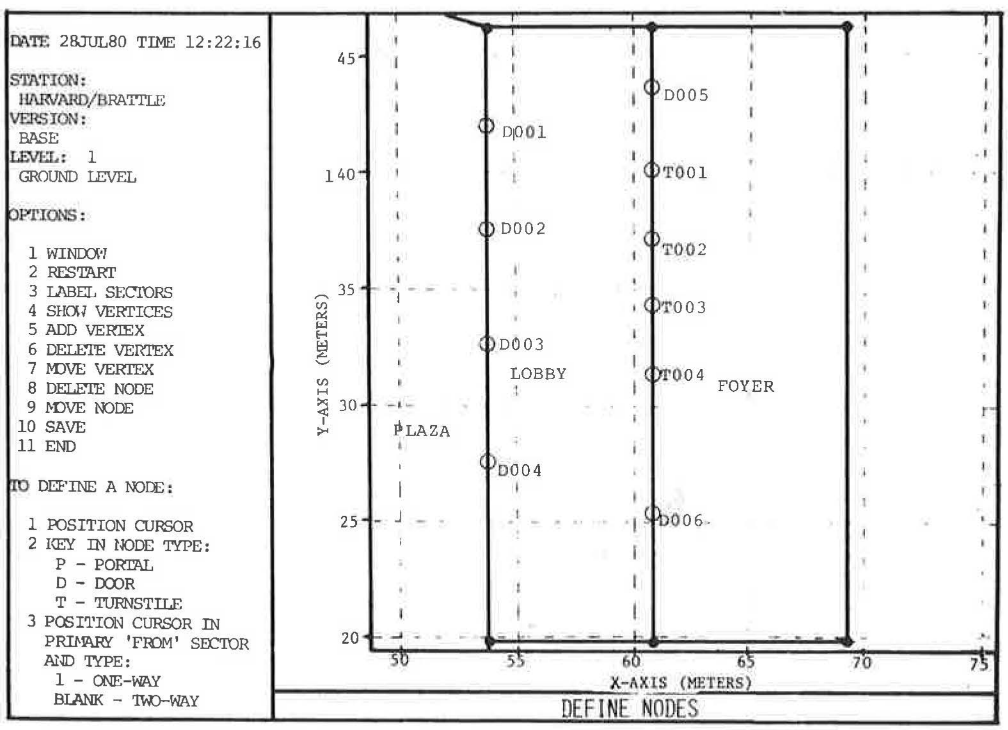


Figure 4. Interactive graphical input display.

modeling of any station in the network. However, this does not imply that a transit network must exist before a station can be modeled: The network modeling capabilities are optional.

The DBMS is responsible for storing data as input, for retrieving it as necessary for use in simulating a station, and for display purposes. It serves as a single file replacing the numerous files that would be required in its absence. As a central repository for information describing multiple stations and other entities, it greatly relieves the file-handling burden of the user, promotes the efficient use of data (e.g., one station can be defined in terms of differences from another), and facilitates the comparison of corresponding bodies of information. The existence of the DBMS enables the USS II user to view, for example, time-series displays in which the outputs of several time segments appear together. In short, the DBMS greatly increases the analytic capabilities of USS II while greatly simplifying its use.

Use of Graphics

Since the intended users of USS II--architects and planners--are visually oriented, it was decided that USS II must use graphical displays whenever possible. Consequently, graphics have been incorporated into the USS II design to perform two major functions: to input station structure information and to display simulation results.

USS II does not produce any dynamic graphical displays while the simulation is proceeding, since that type of display would drastically slow the simulation. Within the bounds of static graphics, however, a wide variety of graphical input and output capabilities are available.

All "structural" station information--sector lay-

Figure 5. Mean queue length display.

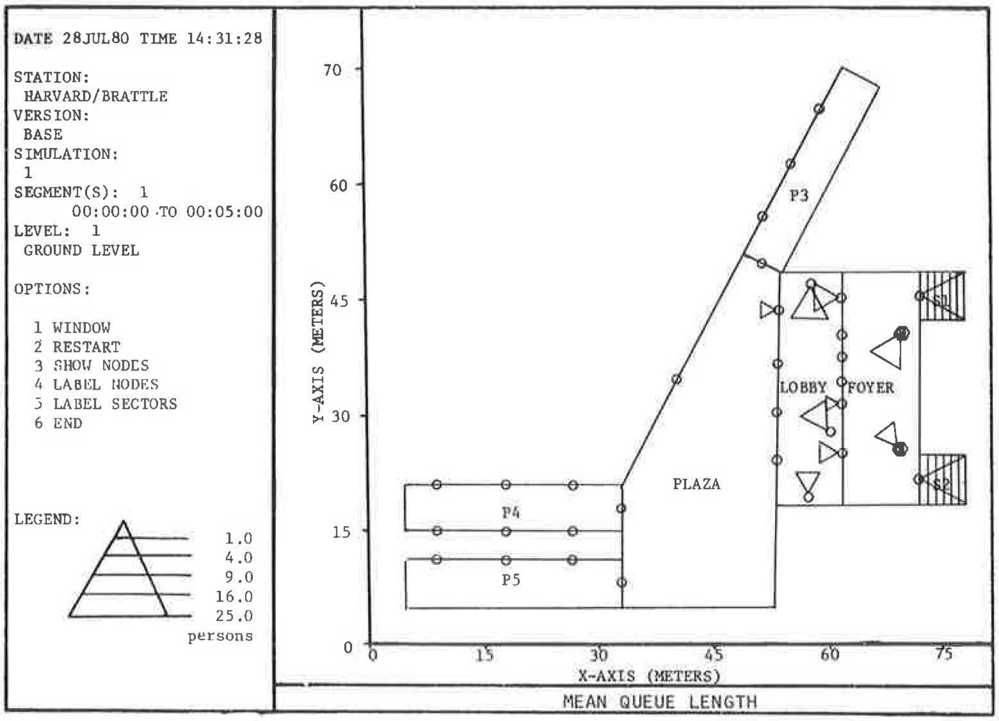
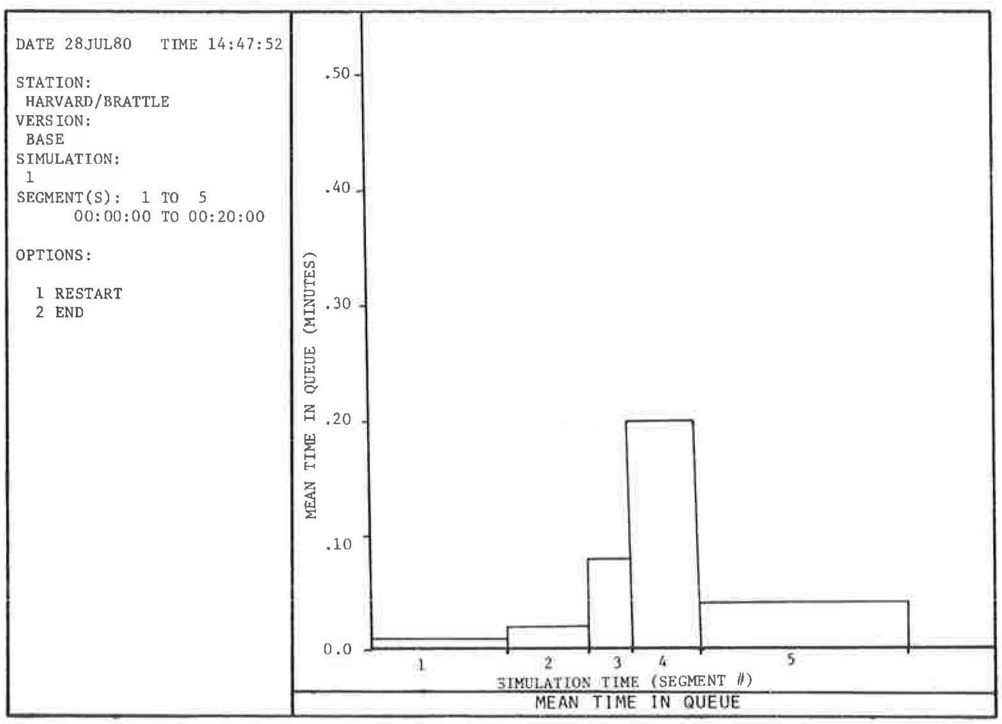


Figure 6. Mean time in queue display.



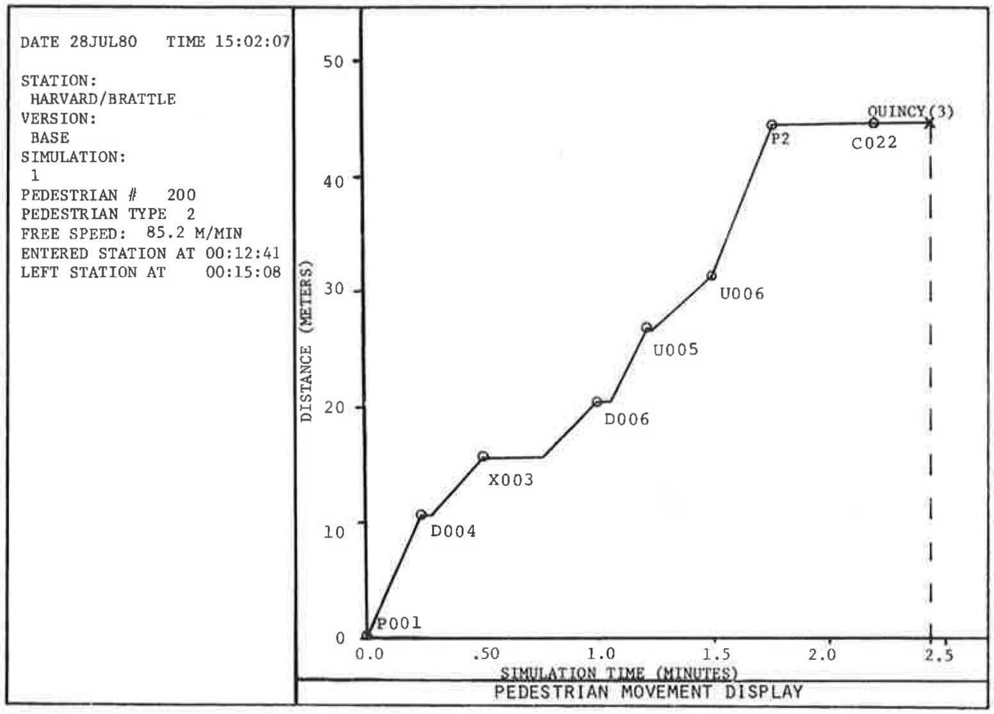
outs and node locations and types--is input graphically. Each level in the station is defined independently and then the levels are connected by the placement of elevators, stairways, ramps, and escalators. Figure 4 shows how the CRT screen may look during the graphical input process.

Many types of graphical outputs are also provided by USS II. Some of the major ones are described below.

A mean queue length display is shown in Figure 5. This display is available for each level within a station. Similar displays are available for cumulative mean queue length and current queue length. Windowing is available for this display (and all other station-based displays) to permit concentration on a portion of a level.

A mean time in queue display is shown in Figure 6. It shows how the mean time in queue has varied over several time segments for the station as a whole. Similar displays are available for time in motion, waiting time, service time, and on-board time. Each display is available for the entire sta-

Figure 7. Pedestrian movement display.



tion, for one level within the station, or for a particular category of components (e.g., queue time resulting from all turnstiles).

Figure 7 shows a pedestrian movement display. This display shows the entire trip of a selected pedestrian and all components of his or her total travel time. This display is extremely useful in verifying the modeling of the station.

USS II can also produce a variety of printed reports. Although it is not included in the current USS II design, consideration is being given to incorporating a general-purpose report generator that would allow the USS II user to design the format and content of all printed reports. In any case, reports would be produced only after the simulation had ended; outputs from the simulation would be limited to short messages.

CONCLUSIONS

This paper has described the major modeling features and environmental characteristics of USS II, the second-generation UMTA transit station simulation program. USS II will offer major improvements over its predecessor, USS I, in terms of expanded station modeling capabilities, more realistic pedestrian movement algorithms, and a more dynamic station-transit interface. Moreover, USS II should be significantly easier to use, since it requires fewer user inputs, operates interactively with on-line "help" facilities, uses a DBMS, and has a variety of graphical input and output capabilities.

Unfortunately, USS II is not yet available for use. The design, as discussed in this paper, is not yet complete, and implementation of the design has not yet begun. The intent of this paper is to stimulate discussion on the design at an early phase in the development.

Comments and criticisms are solicited. Additional details of the USS II design are available on request.

ACKNOWLEDGMENT

This paper was produced under the sponsorship of the UMTA Office of Planning Methods and Support.

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Discussion

Gregory P. Benz

The most important improvement in the USS program, as described by Albright and Couture, will be its ability to be used interactively and its development of graphic input and output. Other improvements, such as the modeling of the dynamic docking of vehicles, should be particularly useful for applications involving bus depots and downtown people mover/automated guideway transit (DPM/AGT) stations. The ability to simulate DPM/AGT stations is particularly important because the close headways of the vehicles make simulation analysis of stations almost imperative.

Designating waiting areas as separate from loading areas should help to overcome a problem that was prevalent in the earlier version of the model. Pedestrian behavior, as handled by the USS program's path-choice model, was always one of finding the shortest path, which is true for most of the station network. However, on the platform a different type of behavior takes over, particularly if the vehicle is not waiting at the platform. USS should now be able to simulate this non-minimum-path type of behavior.

These improvements, as well as giving USS the ability to operate interactively, should result in a vastly improved and easier-to-use model. An improved USS program should be a valuable tool for station designers and planners. The model can help in the sizing of stations, particularly complex station areas that are difficult to analyze by manual techniques. It can assist in analyzing special situations, such as emergency evacuations. This ability is a significant improvement in the program. In this light, the program could aid in the evaluation of present fire and safety codes and regulations, which, in many cities, are not responsive to the needs of transit systems. The model could also help in developing operating strategies for stations, particularly during construction, maintenance activities, and special situations such as a vehicle breakdown. Simulation models offer a tool for use in sensitivity analysis of station concepts and layouts. This is particularly valuable, given the error that is inherent in patronage forecasts. The simulation model would impose a planning discipline on the user, a discipline that is often lacking. USS requires designers and users to analyze station plans in terms of pedestrian paths through the stations and not just as an arrangement of spaces.

UMTA should continue development of the USS computer program, including demonstration of its capabilities through case studies. If USS helps to reduce the capital cost of just one transit station, UMTA's investment in the computer program would probably be more than recouped.

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

Functional Design Elements for Ferry Terminals

PHILIP A. HABIB AND ROGER P. ROESS

The functional design of ferry terminals requires the exercise of a variety of skills and knowledge from such diverse areas as traffic engineering, pedestrian design, transit planning, and vessel operation. Specific types of ferry services are defined, and research findings are presented on how the terminal should be selected and the facilities planned to accommodate these services. For passenger-only ferry operations, planning guidelines are presented for passenger storage and processing facilities, including parking areas, waiting rooms, gangways, and other terminal elements. For vehicle-ferry terminals, guidelines are presented for toll facilities, vehicle sorting and holding areas, discharge demand needs, and other elements of vehicle-ferry terminals.

In March of 1979, the Transportation Training and Research Center of the Polytechnic Institute of New York was awarded the first year of a proposed three-year study to prepare a manual on the planning and functional design of ferry systems. The study is being funded under the University Research Program of the U.S. Maritime Administration. The first year of the study (1) focused on issues of functional design of various system elements. This paper treats these aspects with respect to the complex interface between the vessel and land: the ferry terminal.

CLASSIFICATION OF FERRY SERVICES

There are distinct relations between various characteristics of the ferry service provided and the internal environment that the terminal will require. The project has resulted in the identification of the following list of such characteristics: mode and purpose of ferry service, range and number of stops, frequency of service, and ferry capacity and design.

Mode of Ferry Service

The planning and design of the terminal are controlled by the mode of service provided. The principal modes are (a) passenger only and (b) vehicles and passengers ("passenger" denotes a walk-on rider without a vehicle).

Terminals that service "passenger-only" ferries (i.e., those that carry no vehicles) generally require large park-and-ride facilities as well as efficient transit access. In terminals that serve vehicles as well as passengers, smaller park-and-ride facilities are needed. The major element of ferry terminals that serve vehicles is the extensive amount of holding space required for the sorting and queuing of waiting vehicles.

Purpose of Ferry Service

There is a general relation between the principal purpose of a ferry service and the mode as defined above. The principal purposes of ferry services are commuter journey to work, recreational, and maintenance.

The commuter ferry services generally have a downtown urban center as their base. These ferry services are inclined to have a higher percentage (up to 100 percent) of walk-on passengers who access the terminal by various means. The recreational service, on the other hand, is primarily vehicle oriented and may also carry a moderate number of bicycles. The maintenance service is a mixture of all purposes, including journey to work, delivery of essential services and freight, and recreational trip making. The maintenance purpose applies to routes that service relatively isolated (with respect to land access) locations and effectively "maintains" the principal connection to nearby population centers.

Range of Service

The range of the service describes the total one-way trip length (in terms of travel time) and the number of intermediate stops (destinations). The longer the range and the more numerous the destinations, the more complicated is the vehicle loading-unloading process at the terminal. This process ensures that vehicles can get off in sequence at each stop along the route.

Figure 1. Flowchart for passenger-only ferry terminal.

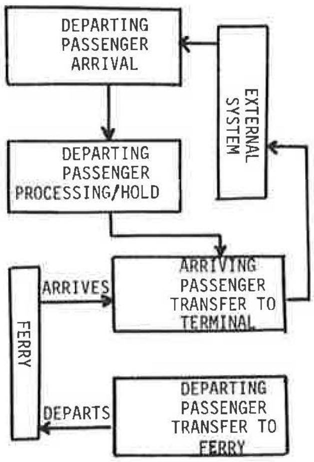


Figure 2. Passenger flow separation at Vancouver SEABUS terminal.

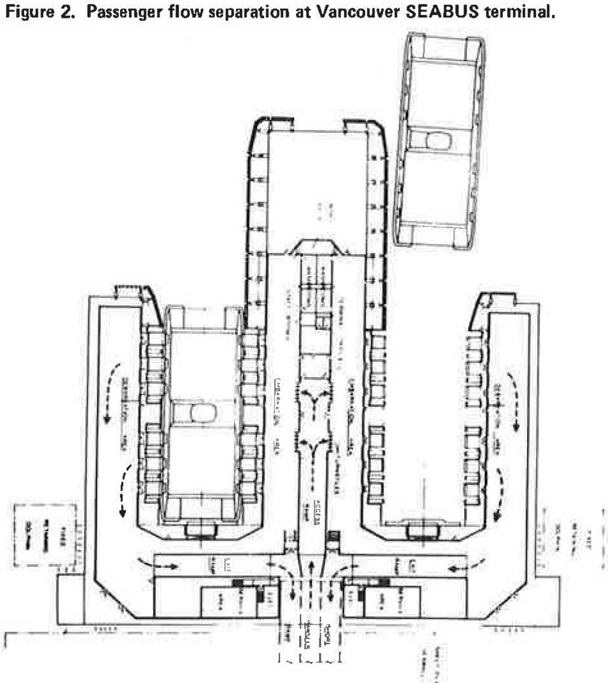
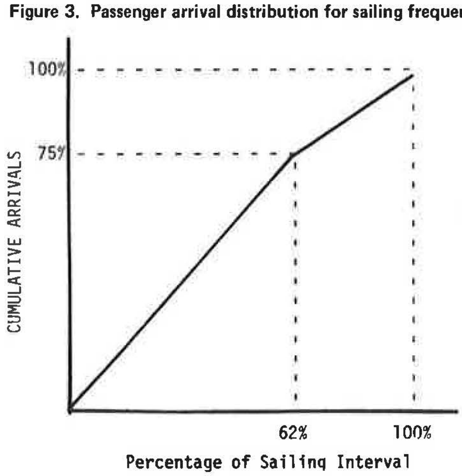


Figure 3. Passenger arrival distribution for sailing frequencies of 30-90 min.



Frequency of Service

The frequency of service in each route used by the terminal is defined by the interarrival time of the ferries. The arrival pattern for vehicles and pedestrians at ferry terminals is controlled by the frequency of scheduled departures. The lower the frequency, the earlier passengers and vehicles will generally arrive at the terminal.

Vessel Capacity and Design

The design features of the vessels also control the functional as well as the detailed design elements of the ferry terminal. End-loading ferries have different terminal needs than do side-loading ferries. In practice, end-loading ferries have achieved wider acceptance for vehicle-carrying ferries, and side loading has been the most accepted design for passenger-only ferries. The discharge characteristics of all ferries will control the processing compatibility of the terminal for both passengers and vehicles. The size of the ferry, in terms of its passenger and/or vehicle capacity, directly controls the scale of the terminal holding facilities.

PLANNING AND DESIGN ELEMENTS FOR PASSENGER-ONLY TERMINALS

The general flowchart for a passenger-only ferry terminal is shown in Figure 1. The departing passenger can access the terminal by various means, including walking (or bicycling), transit (all forms), park-and-ride, taxi, and kiss-and-ride. The departing passenger is processed (if necessary) through turnstiles to a holding area. Depending on the demand at the terminal and climatic conditions, the holding area may be an enclosed structure. When a ferry arrives, arriving passengers disembark first, after which departing passengers are loaded onto the ferry. For most passenger-only operations, the arriving passenger flows have complete physical and temporal separation from the departing flows for control and ease of movements. Figure 2 shows this physical flow separation for the Vancouver SEABUS ferry service.

The departing passengers leave the terminal by various means. When the terminal is in (or near) the downtown, the predominant mode is walk or transit. For instance, at the Manhattan end of the Staten Island Ferry, the split for passengers is 61 percent walk, 37 percent transit, and 2 percent automobile-taxi. Where the terminal site is outlying, the predominant modes are usually park-and-ride and kiss-and-ride as well as transit.

Landside Terminal Access Facilities

The interface between the existing road system and the terminal is generally one or more at-grade intersections. The number and operation of these intersections are governed by the use of automobiles and buses to access the terminal. The automobile population consists primarily of park-and-ride users, but kiss-and-ride and employee traffic are also present.

The design and operation of the intersections are governed by peak traffic flows, both through on the arterial and into and out of the terminal. The traffic pattern, in turn, is governed by the sailing interval of the ferries. For intervals of 30 min or less, a uniform distribution of arrivals (over the 30 min) can be expected. However, data from British Columbia Ferries indicate that, where the sailing interval is 30 min or more, approximately 75 percent of the departures arrive in the first 62 percent of the interval between successive scheduled sailings. Figure 3 shows this arrival pattern.

Figure 4. Theoretical layout of maximum-sized park-and-ride lot.

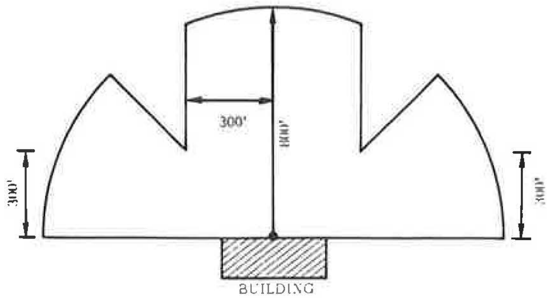
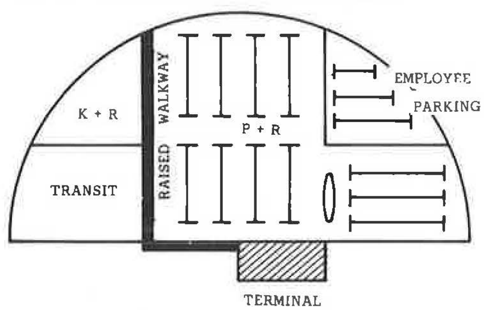


Figure 5. Field applications of hat-shaped layout.



Vehicle departures from the terminal peak more severely than arrivals. Each ferry that discharges park-and-ride users will cause automobiles to arrive at the intersection in the outbound direction at an average rate, which is controlled by the processing capabilities of the terminal and the ferry interface. As passengers discharge from the vessels, usually in the batch mode, the planner should calculate the processing rates of key terminal elements (stairways, ramps, and doorways) along the path from the vessel to the parking lot to determine the expected arrival rate of passengers to their automobiles.

The ability to discharge vehicles rapidly from the terminal to the land-access system is not necessarily critical. The planner should review the capabilities of intersections near the terminal to handle the additional loading rate. The limited use of the terminal as a "reservoir" to dampen the discharge rate of vehicles onto the access system should be considered where necessary, practical, and/or in the community interest.

Parking Facilities

In a passenger-only terminal, parking facilities must be provided for park-and-ride, kiss-and-ride, employees, local transit, and the handicapped.

The demand forecast provides the basis for estimating the number of park-and-ride spaces needed in the terminal. The demand forecast also assumes a terminal "level of service" with respect to parking facilities. The number of spaces is based on the maximum accumulation of vehicles expected over the service day, considering the total number of park-and-ride users expected, their arrival patterns, and automobile occupancy. The final layout will be governed primarily by the shape of the available land. However, several features of the parking area can be controlled by the terminal planner. The set objectives to be used in guiding the planner are

1. To minimize walking distance from automobile to ferry,
2. To minimize walking conflicts with other automobiles, and
3. To maximize the use of available land.

Pedestrian walking distance should be kept to a desirable maximum of 244 m (800 ft) where possible and an absolute maximum of 305 m (1000 ft). Lots that require a walking distance in excess of 305 m from the extremity to the ferry building should not be considered, and the feasibility of a garage should be investigated. In order to minimize pedestrian conflicts, the aisles of the parking layout should be perpendicular to the shoreline (or ferry building). Aisles that are parallel to the shoreline provide minimum safety due to the number of potential conflicts between pedestrians and circulation automobiles.

Figure 4 shows the theoretical layout of a park-and-ride lot for a ferry terminal that satisfies the following criteria: (a) maximum walking distance of 305 m and (b) directness coefficient (ratio of walking path to aerial path) of 1.3.

The "hat-shaped" layout shown in Figure 5 does imply an inefficient use of a symmetrical lot, but it provides a high quality of pedestrian service. The terminal planner should try to adapt the theoretical criteria to actual field conditions. In the adaptation shown in Figure 5, transit facilities, employee parking, and kiss-and-ride are all incorporated with the park-and-ride scheme.

The layout of the individual parking stalls should recognize that automobiles are being downsized. It should also be noted that, for this type of parking facility, the stall turnover rate would be barely more than one per day. Therefore, the stall dimensions should be the smallest allowable for self-parking facilities. Due to the radical mix of automobile sizes at this time, it is necessary to provide parking facilities that can accommodate large and small automobiles simultaneously. This can be accomplished by (a) providing special "small-car" lots and (b) incorporating all automobiles together in the same stall design.

To accomplish the special-lot technique effectively, the planner must adequately estimate the population of large automobiles. Since this population is dynamic, the estimating process will be imprecise. To incorporate both vehicle sizes in the same layout is inefficient, since the "design vehicle" will necessarily be the large automobile.

There is, however, a method that provides a remedy for this problem: the transitional layout. Under this scheme, the desired design vehicle for the long term would be a compact automobile with the following characteristics: 188-cm (74-in) width, 279-cm (110-in) wheelbase, and 508-cm (200-in) overall length. The compact vehicle (not to be confused with the subcompact) requires a parking module (two stalls and aisle) of 16.8 m (55 ft) for two-way operation (90° parking) and a stall width of 2.44 m (8 ft). For the present vehicle mix, a parking module of 18.3 m (60 ft) and a 2.6-m (8.5-ft) stall width are required. Use of the subcompact as the design vehicle, which would require a parking module of 15.24 m (50 ft) for 90° parking, appears to be unattainable for the foreseeable future. In order to accommodate tomorrow's needs in today's design, it is recommended that an angle-parking scheme with a module of 16.8 m be initially striped for use and that, as the complete downsizing of the automobile fleet takes place (1988-1990), restriping for 90° parking be done to correspond to the compact automobile as the design vehicle. Figure 6 shows this transitional parking scheme.

In addition to the parking elements presented above, special parking stalls for the handicapped must be provided at the most accessible locations to

Figure 6. Transitional parking scheme.

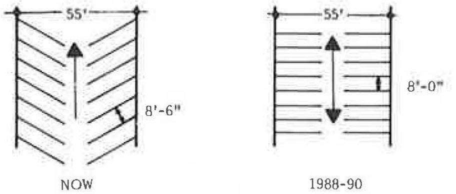


Figure 7. Two-stall configuration for handicapped drivers.

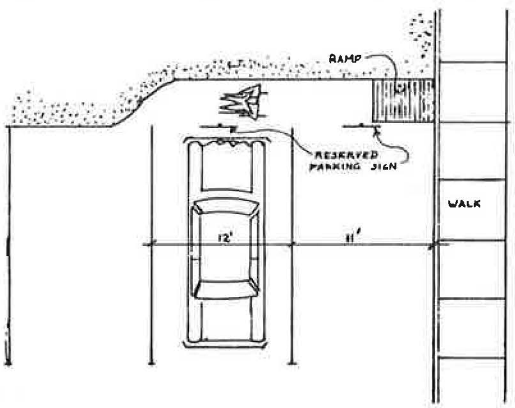


Table 1. Levels of service for pedestrian facilities.

Level of Service	Flow Rate (pedestrians/ft/min) Walkways	Flow Rate (pedestrians/ft/min) Stairs	Storage Area for Waiting Areas and Queues (ft²/pedestrian)
A	<7	<5	>13
B	7-10	5-7	10-13
C	10-15	7-10	7-10
D	15-20	10-13	3-7
E[a]	20-25	13-17	2-3

[a]Capacity.

the terminal building. A minimum of two spaces and a maximum of 2 percent of all spaces should be designated for the handicapped. The parking stalls are 3.66 m (12 ft) wide except adjacent to a walkway, where a 3.35-m (11-ft) stall width is acceptable (4). Such parking spaces must be immediately accessible to the walkway system of the terminal. Figure 7 (4) shows a typical layout for a two-stall configuration.

Pedestrian Facilities

Pedestrian processing and storage are the key functions in the passenger-only terminal. The prerequisite in the development of pedestrian facilities is the development of service standards. Certain qualities of service are mandated by local or federal standards, including requirements related to the handicapped, minimum lighting, and others.

Facilities of special interest are processing facilities and storage facilities for pedestrians. In a ferry terminal, the possible processing facilities are walkways (and gangways), stairs, doors, turnstiles, escalators, and elevators. The pedestrian storage facilities are lounges and other waiting areas.

Levels of service for pedestrians have been established by Fruin (2) and are widely accepted as a base for planning. These levels of service, graded A through F in deteriorating order, give the planner a guide to facility design. Table 1 quantifies these levels of service for walkways, stairs, and waiting (standing) facilities.

It is critical that a pedestrian flow plan for each terminal be developed. It is also critical that it be recognized that passengers are batch unloaded from ferries, which implies that the rate of passengers arriving at the first processing facility (e.g., a walkway or a staircase) is governed by the rate at which the ferry gangways can discharge passengers. As a principal means to minimize in-berth time, passenger-only ferries are designed for a maximum feasible batch discharge rate. Thus, the design of selected processing facilities must be coordinated with the design of the ferry itself.

Since passengers arrive at the ferry terminal in a relatively uniform manner, the facilities provided for processing arriving passengers are of a lesser scale than those provided for batch-discharged passengers. The facilities of principal interest that are provided for accommodating and processing these departing passengers are (a) turnstiles at some point in the flow process, (b) a holding area for passengers, and (c) a facility for processing passengers from the holding area to the ferry.

Turnstiles provide a means of fare control as well as for accumulating passenger statistics. The following are expected processing rates per turnstile:

Type of Admission or Exit	Rate (persons/min)
Free	40-60
Single coin or token operated	25-40
Double coin operated	15-25

Lounges and other waiting areas for passengers are essential for most high-volume ferry operations. Where the service interval is 15-20 min, only a moderate percentage (20-40 percent) of seating need be provided for waiting passengers. When the sailing interval is longer than 20 min, a gradual increase in seating should be provided to ensure a high quality of service. The maximum seating should be based on a selected maximum allowable standing time for passengers. The literature is void in this respect. As a general rule, however, 15 min appears to be a tolerable maximum.

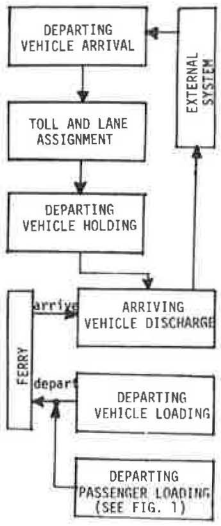
The method for estimating seating requirements is as follows: Determine the sailing interval to be T min. T - 15 is the time after which guaranteed seating may not be provided. (T - 15)/T is the portion of the sailing interval for which seating is provided. By using Figure 3, determine the percentage of passengers arriving in this portion of the sailing interval. This percentage multiplied by the expected departures determines the necessary seating.

The terminal planner can select a different maximum standing time to conform to another quality of service (other than the 15-min maximum) that needs to be provided or to conform to budgetary constraints (or the lack of them).

Other Processing Facilities for the Elderly and Handicapped

Standards of the American National Standards Institute (ANSI) and its amendments relating to accessibility for the handicapped must be built into U.S. ferry terminals that are financed in part with federal funds. Almost all states in the union have

Figure 8. Flowchart for vehicle-ferry terminal.



their "barrier-free" standards, which, essentially, are replicas of the ANSI standards. Fully accessible terminals are one of the design goals in the planning design process. Thus, the terminal must incorporate ramps or elevator alternatives to stairways, provide facilities for the handicapped in restrooms, and provide wheelchair capacity on vessels and in waiting areas.

Detailed design criteria and standards for the handicapped are given in a report by the Eastern Paralyzed Veterans Association (4).

Transit Access

Depending on the extent of use of park-and-ride and/or kiss-and-ride, transit may play a significant role in serving passengers. Facilities for buses are usually provided in a separate area but may be on the perimeter of parking areas closest to the terminal. The walking distance from transit to the terminal should be minimized, and bus schedules and ferry schedules should be carefully coordinated.

PLANNING AND DESIGN ELEMENTS OF VEHICLE-FERRY TERMINALS

The vast majority of ferry operations in North America are vehicle ferries that transport automobiles, buses, trucks, and bicycles as well as walk-on passengers. The layout of a vehicle ferry terminal is conceptually different from that of a passenger-only ferry terminal. Although the passenger components are similar, the vehicle storage and processing (VSP) operations at a vehicle terminal are radically different, especially if multidestination services are offered.

The layout of VSP facilities is done to ensure (a) a minimum amount of in-berth time for the ferry and (b) an effective use of the available land. By their nature, vehicle-ferry terminals are more expansive than passenger-only operations. Figure 8 shows a flowchart for a typical vehicle-ferry terminal.

The departing vehicle accesses the terminal through an intersection with the access road system. In selected terminals, when a road extension (sometimes as much as a mile) has to be built from the proposed terminal site to the existing road system, terminal access is gained via a toll facility placed directly on this extension. The need to construct a new road to gain accessibility to a terminal site is a negative attribute of that particular site. However, such a road does provide a contingency backup storage function that, in general, reduces the ultimate size of the terminal itself.

At the toll facility, the appropriate charge is made and the vehicle is routed to a specific holding (stacking) lane. The vehicles are stored in the stacking lanes until the appropriate ferry is ready for loading. The arriving ferry first discharges vehicles destined for the terminal (which may not be all of the on-board vehicles) and then loads vehicles from the holding area. In cases where multiple stops are scheduled on a particular route, only a limited number of vehicles may be allowed to board at any one terminal in order to reserve room for vehicles boarding at downstream terminals.

The principal functional elements of a vehicle-ferry terminal are facilities for vehicle discharge from the ferry, toll collection, vehicle holding and sorting, vehicle parking, and vehicle loading onto the ferry.

Vehicle Discharge from Ferry

The discharge of vehicles from a ferry must be addressed from two viewpoints: (a) circulation within the terminal and (b) exit onto the external road system. The circulation pattern of discharged vehicles should be separated from other flows in the terminal in order to ensure a safe and expeditious discharge. Once they make their way through the terminal, the vehicles must be transferred to the adjacent road system. Most terminals will have one exit point to the adjacent system.

The objective in laying out the exit intersection is to ensure that its processing capacity is greater than the discharge demand from the ferry. This is especially true for vessels carrying 150 or more vehicles. Queuing cannot be tolerated in most vehicle terminals due to the rapidity with which the ferries must discharge and load vehicles. Therefore, the planner should conservatively assume that 40 percent of the signal green time at the exit intersection will be available for terminal discharge at "urban" terminals and 50 percent at outlying terminals. Each approach lane can therefore process 600-750 vehicles/h. Although these rates may seem high, consider that vehicles being discharged from a ferry at 3.5-s headways (per ramp lane) will result in a demand at the intersection of slightly more than 1000 vehicles/h/lane, which is greater than the capacity of each approach lane at the intersection. It is therefore recommended that, for planning purposes, two approach lanes be provided for ferries discharging from a one-lane ramp and three approach lanes be provided for ferries that discharge vehicles from a double-lane ramp. These requirements should be adjusted to conform with the geometry of the external roadway system and with the actual turning movement anticipated at the exit intersection.

As an example, the vehicle ferry terminal in Seattle, Washington, handles discharged vehicles from a two-lane ramp exiting each ferry. Significant queues will build up at this exit intersection. In most cases, due to the location and design of the vehicle (departing) holding area, almost all exiting vehicles must be discharged from the terminal before loading operations can begin.

The prudent terminal planner should also conduct an intersection capacity analysis at all on-street signals in close proximity to the terminal by using the Highway Capacity Manual (5) and Transportation Research Circular 212 (6). It is realistic to assume that queues can build at downstream intersections, causing congestion and disruption within the terminal itself. A 200-car ferry has a standing queue capacity of 610 m (2000 ft) in each of two adjacent lanes. Where intersection capacity is exceeded, backups into the vessel itself can easily occur.

Toll-Collection Facilities

The principal functions of toll facilities at ferry terminals are fare collection and destination identification. The latter function is critical in order that vehicles can be stored in an orderly manner before loading. Most ferry fares are controlled by vehicle type, number of passengers, and destination. Considerable time is consumed in processing vehicles through such toll facilities. For the simplest of cash operations (only one destination), a mean of 30 s/transaction can be assumed. For multidestination ferry services, especially on recreational routes, the mean time per transaction can range up to 2 min. For ferry operations in which monthly passes are sold, the average time per transaction at these booths may be as little as 10 s except when the new monthly pass is being purchased.

The need to establish a planning guide for toll processing is not critical except for very large terminals, which may be processing 300-400 vehicles/h for several different routes. Based on conversation with various ferry operators, a mean processing rate of 60 vehicles/h/tollbooth is recommended for multidestination service and 120 vehicles/h/tollbooth is recommended for a single-destination service.

The number of tollbooths needed at any one time can be calculated from the demand forecast. The maximum number of toll facilities needed can be calculated by assuming 100 percent occupancy of each scheduled departing ferry. The location (and number) of these toll facilities should ideally be such that queues never back up out to the access road system.

Vehicle Storage and Processing

After proceeding through the toll facility, the vehicles are stored in a holding area until the appropriate ferry is to be loaded. The operations of this holding area become increasingly complicated as the number of possible destinations increases. In the simplest case, a one-route-destination service, vehicles are stored on a first-come-first-served (FCFS) basis by vehicle type (usually automobile versus trucks and buses). There is a need to segregate large vehicles from automobiles because in most ferries trucks and buses are carried in special parts of the vessel.

A more complicated case is a single route with multiple destinations. Vehicles must be ordered in the ferry by sequential destination. Thus, storage in the terminal must be segregated by FCFS, vehicle type, and destination. When a terminal services more than one route (with and without multiple destinations per route), vehicle holding must be done by FCFS, vehicle type, destination, and route. In addition, due to unequal demands and ferry sizes per route (or even within a route), control of the holding area of a vehicle terminal can be an enormous task. Figure 9 shows an aerial view of a multiroute, multidestination ferry terminal on the British Columbia Ferries system.

The layout of the holding facilities is destination sensitive. Data from British Columbia Ferries show that drivers will arrive as much as 100 min before a scheduled departure. For departures more frequent than every 110 min, Figure 3 can be used to determine the arrival pattern. The demand forecast, the sailing frequency, and the size of the vessel all interact to control the size and layout of the storage facility. Storage is commonly accomplished by using parallel stacking lanes 3.35-3.56 m (11-12 ft) wide.

The objectives of the design for the layout of stacking lanes are (a) to accommodate the maximum accumulation for each destination in a whole number of stacking lanes and (b) to minimize the wasted space for each layout configuration. It is generally true that the shorter the length of the stacking lanes, the less will be the overall unused space. The following example shows one recommended method for determining the number and length of stacking lanes in a vehicle-ferry terminal.

Consider a ferry terminal serving two distinct routes that carry automobiles only (for problem simplicity). Route A is a direct route to city X, and route B is a one-stop route to city Y. The demand forecast and the projected sailing schedule provide the planner with the means of predicting an accumulation pattern by destination. The table below gives such an accumulation pattern for this problem. Route A leaves every hour on the half hour, and route B leaves every hour on the hour:

Time (a.m.)	No. of Automobiles: Route A, City X	Route B: Stop 1	Route B: City Y
8:00	100	80	150
8:15	150	20	30
8:30	200	40	65
8:45	50	60	95
9:00	100	70	130
9:15	150	15	30
9:30	200	30	60
9:45	40	45	90
10:00	80	60	120

The maximum length of a stacking lane will be controlled by the physical layout of the available land. The maximum number of stacking lanes is also constrained by the geometry of the terminal land area. In this example, stacking-lane length can range up to 40 cars and the maximum number of lanes is 15. From the practical viewpoint, the minimum length of a stacking lane should be 15 cars for most terminal conditions in order to reduce the expanse of the holding area and to maintain visual control over this area.

The solution to the problem is iterative. The planner begins with the minimum stacking-lane length of 15 cars and determines the number of lanes required for this configuration. The planner increments the length by 5 cars until a solution is found within the defined constraints. Table 2 gives the number of stacking lanes required for lengths of 15, 20, and 25 cars. These results are summarized below:

Lane Length (no. of cars)	No. of Lanes	Time (a.m.)
15	23	8:00
20	17	8:00
25	14	8:00

An acceptable solution is reached with the 25-car stacking-lane length, with minimum total requirement of 14 such lanes.

It is clear to the reader that scheduling of service will have a critical effect on the number and use of the stacking lanes, especially in multidestination terminals. In addition, the planner should also conduct an evaluation of the design and layout under conditions in which one or more sailings are late. This latter evaluation is conducted in the same way as that presented above, but the

Figure 9. Multiroute, multidestination ferry terminal.

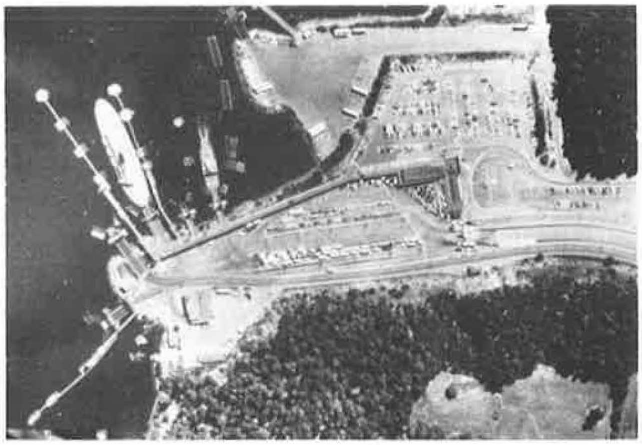


Table 2. Number of stacking lanes required for lane lengths of 15, 20, and 25 cars.

Time (a.m.)	Route A, City X			Route B Stop 1			Route B City Y		
	15	20	25	15	20	25	15	20	25
8:00	7	5	4	6	4	4	10	8	6
8:15	10	8	6	2	1	1	2	2	2
8:30	14	10	8	3	2	2	5	4	3
8:45	4	3	2	4	3	3	7	5	4
9:00	7	5	4	5	4	3	9	7	6
9:15	10	8	6	1	1	1	2	2	2
9:30	14	10	8	2	2	2	4	3	3
9:45	3	2	2	3	3	2	6	5	4
10:00	6	4	3	4	3	3	8	6	6

accumulation for each scheduled departure is carried forward by a specified length of time. The prudent planner will design a terminal to accommodate a sailing delay of 15 min for the conditions that determined the optimum design.

Vehicle Parking

Apart from the sorting-holding area for departing vehicles, there are additional parking needs. These include park-and-ride parking, employee parking, kiss-and-ride parking, and bus-transit parking. The need to provide a high quality of passenger service at a vehicle ferry terminal is somewhat overshadowed by the need to process vehicles with a maximum of efficiency. Therefore, the placement park-and-ride and kiss-and-ride parking facilities will generally not conform to the criteria suggested for passenger-only terminals.

The layout of the parking facilities for a vehicle terminal eliminates most pedestrian-vehicle conflicts. Pedestrians include passengers walking from park-and-ride and kiss-and-ride to the terminal building, passengers who leave their cars temporarily in the vehicle holding area to seek refreshments in the terminal building, and employees. It is desirable to consolidate all pedestrian demand on one side of the terminal grounds and to have this demand access the terminal building without crossing traffic flows. In order to satisfy these objectives, the planner should coordinate building location and parking field layout to minimize design difficulties.

Vehicle Loading

The transfer of vehicles from the holding area to the appropriate ferry should be an efficient and direct operation. The planner should recognize that the loading operation will be manually controlled by "dispatchers". Larger ferries that load from two lanes simultaneously are usually loaded in less time than much smaller ferries that load from one lane. The design of the vessel and on-board control of the loading operation both have more influence on the efficiency of the loading process than the design (location) of the holding area.

Trucks and buses are usually segregated from automobiles in the loading process. The principal reasons are

1. Trucks and buses are routed to wider on-board parking lanes than automobiles;
2. For double-deck ferries, head-room restrictions would be such that trucks and buses could only park in specific portions of the lower parking deck; and
3. To ensure ferry stability by distributing the weight of heavy trucks to both sides of the vessel.

In order to encourage passenger use of vehicle ferries, most ferry operators will assign the highest loading priority to buses. This frequently occurs on a route that serves a large metropolitan center. The planner should ensure that this prioritizing can take place in the layout of the holding area and in the loading operation. It should be noted that vessels are licensed (for safety reasons) to carry a maximum number of passengers at any one time. Where buses frequently use a ferry route, the ferry may leave port half empty of automobiles because the maximum allowable number of passengers has been reached. This usually causes a high degree of frustration for automobile passengers who see the ferry sailing supposedly loaded to capacity.

At larger ferry terminals, where more than one vessel may be simultaneously in port, the layout and operation of the vehicle holding area will generally not allow for simultaneous vehicle loading of ferries. However, provision for an unloading operation from one ferry and a simultaneous loading operation for another should be built into the process. That is, where two ferries are scheduled within 15 min of each other, the terminal manager should route the first arriving ferry to the slip closest to the vehicle holding area. This would ensure that the loading operation of the first arriving ferry can generally occur at the same time as the discharge operation of the later arrival.

SUMMARY AND CONCLUSION

Of necessity, this paper covers only a portion of the material synthesized for the current study. Even the full report can only extract the most pertinent information and criteria. Ferry terminal planning involves the broad use of principles of traffic engineering, pedestrian design, vessel operation, and others. These skills are brought together in a unique type of facility to serve a mode that has great potential.

ACKNOWLEDGMENT

The views, findings, and conclusions expressed here are ours and not necessarily those of the Maritime Administration or any other government agency.

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

Analysis of Rapid Transit Access Mode Choice

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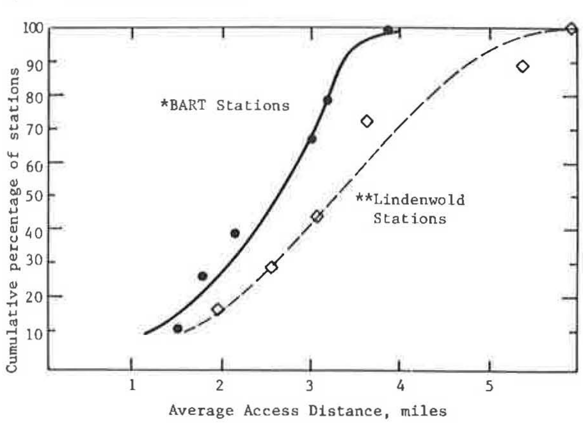
The application of the logit modeling methodology to the development of rapid transit access-mode-choice models that are transferable among different stations in a system is described. Rapid transit stations are classified into groups by using discriminant analysis to test for common behavior at sites within groups and to verify differences in behavior among groups. Eighteen variables are used to define the physical nature and accessibility of the terminal and the socioeconomic structure of the surrounding area. Five station groups are identified: (a) central city; (b) dense residential; (c) predominantly residential, some commercial; (d) predominantly commercial, some residential; and (e) sparse residential and undeveloped land. Multinomial logit access-mode-choice models are described for the different station groups in the Bay Area Rapid Transit system. The modes considered are drive alone, kiss-and-ride, bus, carpool, and walk. An areawide model is compared with the station group models. The results show that models for classified station groups have coefficients that differ from each other and from a model calibrated with the data for all stations in all groups. These models, however, do not offer sufficient uniqueness to justify recommendations. More precise, detailed calibration data are needed to establish transferable models.

This paper reports on the results of the application of the Urban Transportation Planning System (UTPS) ULOGIT calibration program in the analysis of rapid transit access-mode-choice behavior. The choice of mode of arrival at the line-haul rapid transit station for the journey to work was the principal focus of the study.

In spite of the extensive research on and application of travel demand models, few instances have been reported in which the principal focus was on the choice of access mode (1). This is the case because the access-mode-choice scenario is much more complex than the primary-mode-choice situation. For example, a basic problem associated with the use of a model based on a single station in a given area is that parameters are biased by the characteristics of the particular location, environment, station design, and interconnecting modes. On the other hand, a model calibrated with a cross section of data from all of the stations in a system may be representative of no particular station.

The fundamental hypothesis underlying this modeling method is that logit models of access mode choice must consider all viable alternatives and should be constructed in a manner that allows them to be transferred among different areas. The access modes considered in this study are drive alone, kiss-and-ride, bus, carpool, and walk. The data set did not permit consideration of the bicycle and motorcycle as rapid transit access modes. Station location characteristics, together with socioeconomic variables, are used to classify a station in a way that permits logit models to be compared for differences among station types.

Figure 1. Cumulative distribution of average access distance for BART system and Lindenwold Line.



*8 BART Stations: Concord, Pleasant Hill, Rockridge, El Cerrito Del Norte, N. Berkeley, Ashby, Union City, and Bay Fair

**7 Lindenwold HSL Stations: Lindenwold, Ashland, Haddonfield, Westmont, Collingswood, Ferry Ave., and Broadway

STATION INFLUENCE AREA

The average distance of all trips to and from a particular transit station is an indication of the size of the area that the station services. Figure 1 (2) shows the distribution of average distances traveled in accessing eight Bay Area Rapid Transit (BART) stations and seven stations on the Lindenwold High-Speed Line. The average access travel distances ranged from 2.4 to 6.1 km (1.5-3.8 miles) and 3.1 to 9.1 km (1.9-5.6 miles), respectively, for these two systems. Figure 2 shows the distribution of travel distances for specific access modes.

These data show that the range of access distance differs between systems and among modes. The observed patterns are a result of complex interrelations that complicate the development of a prediction methodology.

An analysis of the data from the BART system and the Lindenwold Line reveals little increase in transit-station trip production when the market area goes beyond 6.5 km (4 miles). Therefore, for the purpose of this study, a distance of 6.5 km from the station is used to define the influence area, the distance from which trips are considered to be attracted to the station.

The station area is defined as the area within

Figure 2. Cumulative percentage of trips by mode versus access distance in miles for eight BART stations.

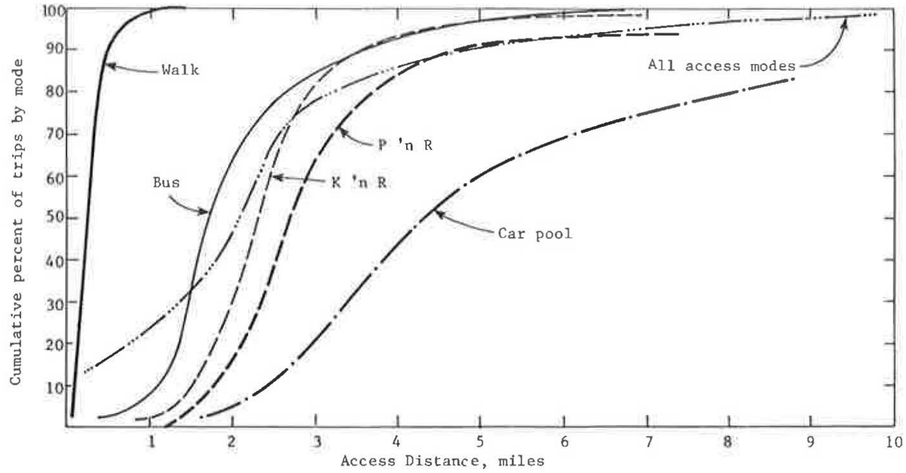


Table 1. Criteria for transit station classification.

Criterion	Analysis Variable[a]	Measurement	Classification
Station type	STTYPE	-	Aerial, surface, subway
Line situation	STSIT	-	Through, transfer, terminal
Station function	STFUNC	A = access trips/peak hour, E = egress trips/peak hour	Attractor (E > 1.1A), generator (A < 1.1E), balanced (0.9E ≤ A ≤ 1.1E)
Station volume	STVOLM	T = daily trips/station	High volume (T > 25 000), medium volume (10 000 < T ≤ 25 000), low volume (T ≤ 10 000)
Parking capacity and use	STPARK	P = occupied spaces/total spaces available	Available (P ≤ 0.75), difficult to find (0.75 < P ≤ 1.0), unavailable (no space provided)
Automobile accessibility	AUTOAC	AC = accessibility index	Good accessibility (AC > 2), fair accessibility (0 < AC ≤ 2), poor accessibility (AC ≤ 0)
Pedestrian accessibility	WALKAC	AC = accessibility index	Good accessibility (AC > 2), fair accessibility (0 < AC ≤ 2), poor accessibility (AC ≤ 0)
Bus accessibility	BUSAC	N = buses/peak hour	Poor service (N < 25), fair service (25 < N ≤ 100), good service (N > 100)
Family income	INCOME	I = mean family income	Low income (I ≤ 10 000), middle (10 000 < I ≤ 15 000), upper-middle (I > 15 000)
Uniformity of income	INCUNI	$U = \sqrt{\sum_{i=1}^{3} (P_i - 33)^2}$	Nonuniform (U > 10), uniform (U ≤ 10)
Gross population density of station area	GPOPDEN	GD = residents/gross station area	Dense (GD > 10 000), intermediate (5000 < GD ≥ 10 000), sparse (GD ≤ 5000)
Net population density of station area	NPOPDEN	ND = residents/residential station area	Dense (ND > 20 000), intermediate (10 000 < ND ≤ 20 000), spare (ND ≤ 10 000)
Racial and ethnic characteristics	RACETH	W% or B% or A% + M% > 90% 70% < W% or B% or A% + M% ≤ 90% W% and B% and A% + M% ≤ 70%	Exclusively white, black, Asian, and Mexican Predominantly white, black, Asian, and Mexican Mixed
Rapid transit service	SRVLEV	H = departures/peak hour	Good service (H > 12), fair service (6 < H ≤ 12), poor service (H ≤ 6)
Land development in station area	LNDUSE	Total land use per category exceeds 40%	Industrial, service, residential, composite, other
Gross population density of influence area	GINFL	GP = residents/gross influence area	Dense (GP > 10 000), intermediate (5000 < GP ≤ 10 000), sparse (GP ≤ 5000)
Net population density of influence area	NINFL	NP = residents/residential influence area	Dense (NP > 20 000), intermediate (10 000 < NP ≤ 20 000), sparse (NP ≤ 10 000)
Land use development in influence area	LUINFL	Category based on percentage land use	Basic industrial, service, residential, composite, others, all > 40 percent

[a]Variable names used during computer analysis.

0.8 km (0.5 mile) of the station and is used to characterize the area within walking distance of the station (2).

STATION CLASSIFICATION METHODOLOGY

The parameters given in Table 1 vary among transit stations and are used to initiate comparative analyses of rapid transit access-mode-choice behavior. These variables include socioeconomic data for each jurisdictional area, aerial photographs, land use data for 440 traffic zones in the Bay Area, BART system data, and access trip data for each station (3,4). The majority of these measures were cited in the BART Residential Impact Study (5).

These data were then evaluated with regard to the criteria given in Table 1 and translated into ordinal values for analysis purposes (2). These ordinal values for each variable served as input to statistical routines used to establish station classes.

Although no two rapid transit stations are identical, all stations exhibit common transit-related characteristics and some stations share a sufficient number of these characteristics to be considered equivalent for the purpose of access-mode analysis. Furthermore, the inclusion of sufficient station characteristics to clearly define a classification for a station permits the identification of station types independent of geographic location, a premise essential to the solution of the transferability issue.

Data related to the characteristics that appear

Table 2. BART station groups by type.

Type	Category	Station No.	Station Name	No. of Observations	No. of Home-Based Work Trips
1	Highly urbanized	11	Berkeley	330	133
		21	Lake Merritt	329	126
		23	19th Street	329	88
		24	12th Street	328	79
		30	Mission and 16th Street	330	145
		31	Civic Center	327	104
		32	Powell Street	328	92
2	Predominantly single-family dwellings	1	Concord	330	229
		6	Rockridge	326	173
		7	Richmond	330	200
		9	El Cerrito Plaza	330	201
		10	North Berkeley	330	181
		12	Ashby	329	161
		15	South Hayward	329	217
		22	MacArthur	327	157
		26	Dale City	329	225
		27	Balboa Park	330	193
		28	Glen Park	330	223
		29	24th Street and Mission	329	160
3	Single-family dwellings with some commercial property	2	Pleasant Hill	330	235
		3	Walnut Creek	329	236
		4	Lafayette	330	234
		8	El Cerrito del Norte	326	224
		16	Hayward	329	177
		17	Bayfair	329	222
4	Commercial property with some single-family dwellings	18	San Leandro	330	184
		19	Coliseum	330	147
		20	Fruitvale	330	184
		25	Oakland West	330	164
5	Sparse residential development with undeveloped land	5	Orinda	329	205
		13	Fremont	328	205
		14	Union City	330	233

to distinguish the 34 BART stations were compiled. Of the 18 distinguishable variables described in Table 1, as few as 10 can be used to identify well-defined station classes. The relative importance of these variables was established during the analysis and is given below:

Rank	Variable	F-Ratio
1	NINFL	17.162 56
2	STFUNC	8.933 39
3	STTYPE	5.707 35
4	BUSAC	5.344 24
5	GPOPDEN	4.713 57
6	GINFL	1.997 36
7	STPARK	3.481 48
8	INCOME	3.295 65
9	AUTOAC	3.247 46
10	LUINFL	3.160 75
11	STSIT	2.285 29
12	INCUNI	1.941 81
13	SRVLEV	2.291 08
14	NPOPDEN	1.428 90
15	RACETH	3.243 15
16	STVOLM	0.598 62
17	WALKAC	0.402 91
18	LNDUSE	0.183 76

An initial hypothesis as to the most practical number of groups and their respective memberships was formulated by inspection of aerial photographs of the stations (3). Five groups were selected based on the subjective criteria: (a) central city; (b) dense residential; (c) predominantly residential, some commercial; (d) predominantly commercial, some residential; and (e) sparse residential and undeveloped land. This hypothesis was then tested by using the discriminant analysis program contained in the Statistical Package for the Social Sciences (6). Visually, some of the stations exhibited characteristics of two groups, and proper initial classification was difficult to determine. The analysis results were examined, and the hypothesis was modified until visual and numerical data strongly supported the classification hypothesis. The groups are given in Table 2.

MODEL DEVELOPMENT

Model Description

With the stations grouped into five classes, it was further hypothesized that access-mode-choice models for each of these classes would be significantly different from all other class models. In addition, the performance of these five models should exceed that of a model developed without regard to station class. This aspect of the classification hypothesis was also explored.

Although a comprehensive access-mode-choice model design would explore the significance of the many potentially relevant variables, this modeling effort was limited to the variables available from the 1975 BART Passenger Profile Survey. That survey provided the following:

1. Trip-maker variables--Age, sex, race, education, income, and automobile availability;
2. Trip-related variables--Purpose, origin, origin time, number of traveling companions, and destination;
3. Automobile-related variables--Trip time and vehicle occupancy; and
4. Transit-related variable--Access travel time.

Not all of these variables proved useful during the calibration trials, nor did all of the variables used prove significant for every station type. For comparative purposes, however, the same model structure was applied to each station type and to the entire BART system. The model structure (i.e., the disutility expressions) is as follows:

LOCAL BUS = D COEF2 * ACCESS DISTANCE
+ T COEF2 * ACCESS TIME
+ AUTO COEF * AUTO AVAILABLE (1)

DRIVE ALONE = D COEF1 * ACCESS DISTANCE
+ T COEF1 * ACCESS TIME
+ AGE COEF * MIDDLE-AGED (2)

CARPOOL = T COEF3 * ACCESS TIME
+ AGE COEF * MIDDLE-AGED (3)

KISS-AND-RIDE = D COEF1 * ACCESS DISTANCE
+ T COEF1 * ACCESS TIME
+ RACE COEF * NONWHITE RACE
+ INCM COEF * LOW INCOME
+ AGE COEF * MIDDLE-AGED (4)

WALK = D COEF3 * ACCESS DISTANCE
+ AUTO COEF * AUTO AVAILABLE (5)

where

LOCAL BUS = local transit to rapid transit station;
ACCESS DISTANCE = calculated distance;
ACCESS TIME = perceived access time (min);
AUTO AVAILABLE = 0 if none available, 1 if available;
DRIVE ALONE = driver parks automobile at rapid transit station;
MIDDLE-AGED = 0 if not, 1 if over 17 and under 65;
CARPOOL = member of group that parks automobile at station;
KISS N RIDE = rider dropped at transit station;
NONWHITE RACE = 0 if white, 1 if race other than white;
LOW INCOME = 0 if not, 1 if income less than or equal to $7000/year; and
WALK = patron walks to rapid transit station.

The access-distance variable was derived from the perceived access-time variables and an estimated speed for each mode. Automobile availability is a perceived variable (i.e., yes or no) and is not a calculated value associated with the number of vehicles owned and number of licensed drivers in the household. The age variable used stratified the population into two groups: those relatively independent in their movement (middle-aged) and those possibly dependent on others for transportation (young and elderly). The income variable chosen (low income) divided the population into those earning more and less than $7000/year. The racial variable (nonwhite race) separated whites from nonwhites.

Model Structure

Models using level-of-service variables--access time and access distance--were developed by using each variable independently (2). The model form was first optimized by using access distance, and then the same model form was used for the access-time-only model by substituting access time for access distance. The model form that uses both access time and access distance was also optimized. For this combined model, unique coefficients for access distance were applied to those modes where the speed used during distance development was appropriate for only that mode. The drive-alone and kiss-and-ride modes share coefficients for both the distance and the time variables in all models, since these modes are identical in these two level-of-service variables. If access cost or driver time was to be used as a calibration variable, it could be argued that drive alone and kiss-and-ride are characterized by different levels of service. However, this argument has been weakened by the realization that many career families drop some household members at the rapid transit station and others continue on to employment destinations. This type of trip compares more favorably with the drive-alone mode than with the kiss-and-ride mode. Speed for the carpool mode is difficult to estimate, since these journeys are a combination of low-speed rider pickup and high-speed line-haul to the station. For this reason, the combined model used access time in the carpool mode and both access time and distance were used in the drive-alone and kiss-and-ride modes. Conversely, for the walk mode, access distance proved to be a much more significant variable than access time.

The local bus and walk modes are the only access modes that do not require an automobile; for these, the automobile-availability variable is a negative influence. The sign of the automobile-availability coefficient should be the same as those of the time and distance coefficients. Similarly, the age variable--middle-aged--could be placed with the local bus and walk modes to exhibit a negative influence; however, it is equally valid to place it in the other three mode expressions as a positive influence. The age coefficient should carry a sign opposite to that of the automobile coefficient.

The race and income variables were both placed in the local bus mode expression of the access-distance and the access-time models. In the combined level-of-service model, these variables performed better in the kiss-and-ride expression. This placement of the race and income variables is difficult to rationalize, although a negative influence by the variables might be expected. The consistently small t-scores exhibited by the variable sex indicated that it was of little value, so it was excluded from the combined model form.

The Models

The results of testing the three proposed model forms by using the station type 2 data are given in Table 3. The following additional measures are provided for comparison:

Model	Percentage Correct	Pseudo R^2	χ^2
Distance	68.9	0.279	9537
Time	55.4	0.110	8877
Time and distance	94.5	0.638	2125

The access-distance model form acts as a poor predictor for the local bus, carpool, and kiss-and-ride modes. The access-time model predicts poorly the local bus, carpool, kiss-and-ride, and walk modes. The combined model form is an excellent predictor for all modes except kiss-and-ride. Accordingly, the combined form was chosen for the rest of the study.

Applying the calibration procedure to the files for each of the five station types and to a calibration file for all of the BART stations taken as one group yields the coefficients given in Table 4. It can be seen from this table that type 1 coefficients differ greatly from the model coefficients of the other station types, whereas for the other models the differences in coefficients are not so readily apparent. As can be seen from the t-statistics, the importance of a given variable can vary greatly from one station-type model to another. The t-statistics for the socioeconomic variables are generally lower than those for the level-of-service variables. The signs of the coefficients are as expected, except for one of the distance coefficients and the age coefficient of the model for station type 1. These two coefficients appear only in the automobile-related modes, which for type 1 (highly urbanized) are greatly underrepresented.

The model statistics for each calibration group are given in Table 5. For each model type and mode, the number of observations, the number correctly identified, and the sum of the probabilities are shown. The following additional measures are provided for comparison:

Station Type	Percentage Correct	Pseudo R^2	χ^2
1	85.9	0.504	1041.1
2	94.5	0.638	2124.9
3	95.5	0.549	1717.6
4	90.6	0.567	780.4
5	92.9	0.533	856.0
All	94.4	0.628	5499.6

All models performed well except for the type 1 model's inability to correctly predict the automobile modes. The kiss-and-ride mode was poorly predicted in every case, which indicated that the calibration data lacked variables sensitive to this mode.

The six models described in Tables 4 and 5 differ significantly and support the hypothesis that station-type classifications provide a basis for developing models that can be transferred to comparable geographic and socioeconomic areas. Because the quality of a logit model is difficult to define, models cannot be readily compared. One of the basic questions to be considered is whether or not the model calibrated by using data from all stations differs significantly from the individual station-type models. This question can be answered by using the likelihood ratio test, which is applied to the null hypothesis that there is no difference between the all-stations model and each of the station type models. The results given in Table 6 indicate that a significant difference does exist. Another basic question to be considered is whether or not the all-stations model is as good a forecasting model as the model designed specifically for the station type. This question is much more difficult to answer due to the variability in the criteria for comparing logit models. One straightforward approach is to review the results of applying the all-stations model to each station-type group as given in Table 6. The following measures are provided for comparison (the critical χ^2 value is 16.9 at 0.05 level of significance with 9 degrees of freedom):

Station Type	Percentage Correct	Pseudo R^2	χ^2	Likelihood Ratio Test
1	94.6	0.723	472.3	485.0
2	94.5	0.641	2114.1	18.6
3	96.0	0.595	1552.4	179.2
4	91.2	0.608	717.8	80.0
5	93.4	0.563	828.9	57.2

Table 3. Comparisons of performance of time, distance, and time-distance models.

Mode	No. Observed	No. Estimated: Distance Model	Time Model	Time and Distance Model
Local bus	265	132	105	263
Drive alone	727	670	703	727
Carpool	156	75	67	156
Kiss-and-ride	345	123	112	239
Walk	576	426	159	573
Total	2069	1426	1146	1958

Table 4. Coefficients for access-mode-choice model by station type.

Variable	1		2		3		4		5		All	
	C	t	C	t	C	t	C	t	C	t	C	t
Access distance												
D COEF1	-0.1776	1.40	2.6989	15.40	2.5519	11.66	2.2355	8.02	2.5883	8.72	2.8632	23.04
D COEF2	0.7125	5.03	5.2282	22.80	4.4968	16.73	4.3925	12.14	4.6910	12.21	5.4986	34.97
D COEF3	2.0632	10.28	8.1549	28.32	5.7975	18.46	5.6596	12.81	5.4963	12.50	8.3385	42.50
Access time												
T COEF1	0.3440	11.63	0.9975	20.23	0.6733	13.33	0.7461	9.09	0.6816	8.46	1.0010	31.71
T COEF2	0.1303	6.44	0.3423	14.96	0.1492	6.12	0.1048	2.96	0.0769	2.21	0.3192	20.43
T COEF3	0.3473	8.95	2.1331	24.83	1.7348	18.01	1.7360	12.44	1.8161	12.57	2.2028	38.18
Automobile availability AUTO COEF	0.4938	2.44	0.8033	3.89	0.8477	3.14	1.3188	3.56	0.5764	1.44	0.9211	6.73
Age (middle) AGE COEF	0.9022	4.49	-0.2270	0.97	-0.8143	2.73	-0.6691	1.65	-1.4595	3.32	-0.2679	1.73
Income (low) INCM COEF	0.2524	0.83	0.7330	3.51	0.6774	2.27	0.5269	1.52	0.3105	0.92	0.5959	4.55
Race (nonwhite) RACE COEF	-0.2416	1.13	0.3939	2.99	0.4868	2.37	0.6122	3.27	0.8930	3.67	0.4580	5.53

Note: C = coefficient, and t = t-statistic.

Table 5. Calibration statistics for access-mode-choice model by station type.

Mode	1		2		3		4		5		All	
	N/N	P	N/N	P	N/N	P	N/N	P	N/N	P	N/N	P
Local bus	266/266	260.9	265/263	336.5	109/105	131.8	103/99	108.1	45/43	53.6	788/783	880.6
Drive alone	91/45	90.9	729/729	549.4	642/642	430.3	302/302	218.3	346/346	243.5	2110/2110	1537.3
Carpool	16/0	56.1	156/156	208.4	82/82	130.6	34/34	50.7	36/36	55.3	324/324	463.0
Kiss-and-ride	86/51	94.7	346/239	469.7	237/189	392.6	110/59	171.8	129/92	204.0	908/628	1333.4
Walk	231/231	187.4	577/573	508.6	140/138	124.5	56/54	56.0	37/34	36.3	1041/1034	954.7
Total	690/593		2073/1960		1210/1156		605/548		593/551		5171/4879	

Note: N/N = number of observations/number correctly predicted, and P = probability sums.

Table 6. Performance of general model for each station type.

Mode	1 N/N	1 P	2 N/N	2 P	3 N/N	3 P	4 N/N	4 P	5 N/N	5 P
Local bus	266/266	244.2	265/262	340.8	109/108	137.9	103/103	98.8	45/44	59.3
Drive alone	91/91	107.4	729/729	557.3	642/642	427.9	302/302	213.6	346/346	231.4
Carpool	16/16	24.7	156/156	206.7	82/82	118.0	34/34	53.0	36/36	60.9
Kiss-and-ride	86/49	86.6	346/239	475.4	237/189	393.5	110/59	175.2	129/92	203.1
Walk	231/231	227.1	577/573	492.5	140/140	132.6	56/54	64.4	37/36	38.3
Total	690/653		2073/1959		1210/1161		605/552		593/554	

Notes: N/N = number of observations/number correctly predicted, and P = probability sums.

The values for pseudo R^2 and total percentage correct are generally higher in Table 6 for the type models than in Table 5. The χ^2 values for the all-stations model were lower than those for all other models, as was anticipated. The probability sums of Table 6 were neither consistently better nor consistently worse than those of the type models. These results make it difficult to determine whether the station-type model is the best in each case.

CONCLUSIONS

Adequate planning for rapid-transit-station facilities is enhanced by the use of access-mode-choice models. The development of an access-mode-choice model for a new site is impractical because the calibration is dependent on unverifiable, subjective data. The apparent solution to this problem is the use of a model developed and verified for an existing station in an area that exhibits characteristics similar to those of the proposed site for the new station. Proper characterization of the proposed station market area is the necessary first step in an effective model transfer. In this study, as few as 10 identifying variables were found to provide the basis for market area classification and the concomitant model selection.

The models developed in this study, although significantly different from each other and from the all-stations model, do not offer sufficient uniqueness to justify their recommendation. All models performed well, and the all-stations model predicted access mode choice for the station groups as well as or better than the individual group models. However, this is similar to the experience concerning aggregate and disaggregate trip-generation models in the forecasting mode (7). Transferable access-mode-choice models will be available only when they can be based on precise, detailed travel and system data. Such was not the case for this study because existing data were used. A more comprehensive set of modeling variables collected by using a questionnaire similar to the one suggested by Korf, Demetsky, and Hoel (2) should provide the desired model uniqueness.

This paper provides a systematic methodology for analyzing and predicting rapid transit access-mode-choice travel behavior (2). It is expected that the methods developed will become refined as further applications of the tools described are implemented.

ACKNOWLEDGMENT

This research was sponsored by the University Research and Training Program of the Urban Mass Transportation Administration. The opinions, findings, and conclusions expressed in this paper are ours and not necessarily those of the sponsoring agencies.

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Discussion

Gregory P. Benz

At the National Conference on Planning and Development of Public Transportation Terminals in Silver Spring, Maryland, in September 1981, access to transportation terminals attracted the most attention and discussion. The virtues of fully integrated bus-rail networks, as seen in Washington, D.C., and Atlanta, were described, and the priority given to various modes of access to stations was argued and debated. Given this interest, the paper by Korf and Demetsky is indeed timely.

The examination of rapid-transit-station access mode choice is an important part of the transportation planning process for several reasons.

The first is capital cost. Acquiring land for and building parking facilities are a substantial part of the total cost of a station. The demand for these facilities needs to be estimated carefully. The consequences of underestimating parking demand in the planning stage and trying to provide parking facilities later can be quite severe.

Another reason is operating cost. Feeder bus lines cost money to operate. Financially strapped transit properties cannot afford to run underused or poorly planned services.

Poor transit and pedestrian access to stations could discourage system ridership, as could inadequate park-and-ride and kiss-and-ride facilities.

And, finally, there are environmental concerns. Those environmental concerns that have local community impacts and are related to station access modes, such as air quality, noise, and traffic congestion, need to be estimated creditably, particularly since more citizens are actively participating in the station-planning process.

Modal-choice models for rapid-transit-station access would bring the planning of this important part of the transit system up to a level of sophistication comparable to the planning for other parts of the system. Such models should relate to and make use of data available from the system planning modal-choice models. Station access models should allow an examination of various supply and demand scenarios and policies, including concerns such as parking availability and cost, feeder transit fares, and frequency of service. Finally, the models should be sensitive to varying supply and demand characteristics of the station environment. Supply refers to the availability of transit service or parking, for instance, and demand refers to the socioeconomic characteristics of the population around the station.

The paper by Korf and Demetsky describes their attempt to develop a rapid transit access-mode-choice model that is sensitive to the geographic and socioeconomic characteristics of the station environment. The authors conclude at the end of their paper that the models they developed do not offer sufficient uniqueness to justify recommending the models. They state that transferable access models will be available only when they can be based on precise, detailed travel and system data. Although I concur with their conclusion, let us look at some features of the models presented by the authors as means of offering some suggestions for future investigations.

STATION INFLUENCE AREA

The study by Korf and Demetsky uses a distance of 6.5 km (4 miles) from the station to define the area from which trips are considered to be attracted to the station. The influence areas of stations vary as a function of station spacing. Stations in highly urbanized areas, such as a central business district, would generally have an influence area of 0.8 km (0.5 mile) or less, whereas the influence areas of stations in suburban areas may approach the 6.5-km distance used in this paper. The effect that different station influence areas have on access mode choice, particularly for the walk mode, needs to be considered.

STATION CLASSIFICATION METHODOLOGY

The authors use a set of criteria for classifying transit stations into groups: highly urbanized, predominantly single-family dwellings, etc. Although many of the criteria used can be applied to existing stations, they may require forecasting a tremendous amount of data for new stations. Station classification criteria that can be readily applied to new stations must be developed. A misclassified station would result in the wrong model being applied and incorrect modal-split estimations.

MODEL DEVELOPMENT

The authors' main purpose was to develop a model for each of the five classes of stations. They use data available from the 1975 BART Passenger Profile Survey. The socioeconomic factors used as independent variables are age, automobile availability, income, and race. The income variable used divides the population into low income and non-low income. The racial variable separates whites from nonwhites. I would think that, historically, nonwhite trip-making behavior has been influenced more by income level than by race. In some geographic areas, I would also think that the low-income and nonwhite variables may be highly correlated. A similar relation may exist between income and automobile availability. The relation of variables such as these should be investigated carefully before they are included in the models.

The level-of-service variables are access time and access distance. Access distance was derived from the perceived access time and an estimated speed for each mode. Although it is not discussed in the paper, the estimated modal speed should vary according to station type. Generally, the more built-up the area, the lower the speed will be. Using a more accurate means of estimating access distance and other variables should, as the authors conclude, improve the models. Including other factors, such as transit fares, walk time to the access mode, and parking cost for automobile modes, would allow planners to test various policies and scenarios.

The authors use a model structure that contains both access time and access distance (which is derived from access time). They state that the superior performance of the combination of these variables in the models outweighs the undesirability of including two highly correlated level-of-service variables. Since distance is calculated from perceived time for each mode, it is conceivable that the coefficients for the time variable should be able to account for the distance variable.

APPLICATION

Since the purpose of developing rapid transit access-mode-choice models is to apply them to the planning process, the planner must be able to forecast the input variables with some degree of certainty. Perceived automobile availability or perceived access time, as used in the paper, would be difficult to forecast. The station access-mode-choice model should try to use the same input that would be used for the system mode-choice analysis.

CONCLUSIONS

The authors conclude that the models they developed do not offer sufficient uniqueness to justify recommending them. Transferable access models will be available only when they can be based on precise, detailed travel and system data. I agree that the major problem with the models is the data base from which they were derived. However, given an improved data base, the methodology used by Korf and Demetsky can be followed to develop rapid transit access-mode-choice models. Improved data, including cost data, should lead to transferable access-mode-choice models that can assist transit station planners.

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

Guidelines for Planning Public Transportation Terminals

LESTER A. HOEL

The considerations necessary in the planning of transit stations from the viewpoint of the transit user and the operator are described. The basic function of a transit station is to process the flow of passengers between modes. A station also serves to attract the user to the system and it provides space for service functions, access, and joint development. Transit stations should be designed for the convenience, comfort, and safety of the passenger. A clearly defined pathway is essential and will reduce the need for information, improve safety and security, and facilitate consumer services. Station operations are enhanced by the provision of sufficient exit and entrance facilities, dependable fare-collection equipment, and adequate platform dimensions. Maintenance should be considered in the planning process, and operating personnel are essential members of the design team. The station design experience of the three major new U.S. systems—San Francisco, Atlanta, and Washington, D.C.—is reviewed, and a brief outline is presented of the elements of a transit-station design methodology that, if used, can assist to incorporate both policy and design considerations into the station design planning process.

The planning and design of intermodal transit facilities are of significant concern in the development of a regional metropolitan rapid transit system. The basic function of a passenger terminal is to process the flow of passengers between modes--that is, to assist in the transfer of passengers from one mode or vehicle to another, in an efficient, convenient, comfortable, and safe manner. The fundamental purpose of a transit station is to transfer passengers between modes within a transportation network (1).

The manner in which a station design is successful in accomplishing its primary purpose, smoothly, continuously, and in a pleasant environment, will strongly influence the degree to which the system is accepted by the riding public. A poorly designed station can affect the advantages of the line-haul rapid transit portion of the trip if the perceived impedances within the station are sufficiently great that they outweigh the gains of the between-station portions of the trip.

Terminal planning and design are especially critical for metropolitan rapid transit since station-to-station times cannot be easily decreased due to the relatively short distances between stations. Thus, the relative effect of access to and transfer through a station is significant and can influence the share of the market attracted to the new system. The simplest transfer is one in which there is no waiting time and the walk between modes is short and direct--for example, from one train to another across a platform or from one bus stop to another. The problem increases in complexity for large, multilevel stations at which several modes interface, including automobile parking and fare-collection barriers.

The fundamental purpose of a transit station--to transfer passengers between modes--should be foremost in the station planning and design process. It is usual to assume that the transit passenger perceives the transfer as taking from 2.5 to 3.0 times the actual time spent waiting. Thus, compromises in the station design that serve to inconvenience the transfer process or create congestion in order to save cost should be avoided. A life-cycle cost approach that considers the use of the station over its useful life will serve to justify additional initial costs for station elements. Among these are wider platforms, shallow stations, and more escalators.

STATION FUNCTIONS AND DEFINITIONS

In the process of carrying out its basic function, which is to assist passengers between modes, the station serves a variety of purposes, each of which can be supportive of the total system objectives. These functions range from attracting users to the system, processing passengers through the station, service functions, and joint development.

To begin with, the station serves as the first image that the traveler has of the system (2). The station exterior acts as the "store front" of the system, creating for the potential user an impression of what might be available inside. Upon the entry of the user into the station, the station serves as a reception center, a place where the customer can inspect and get an impression of the likely quality of the system. The station environment, lighting, decor, cleanliness, sense of security, and general ambiance serve to create an impression of the type and quality of service that the traveler can expect. For example, consider the difference in the effect created by an intercity bus terminal and an intercity airport terminal. In contrast, the new Port Authority of New York and New Jersey bus terminal was designed to operate like an airport terminal. The quality of the station environment immediately creates an impression of the quality of the transportation service provided.

As one proceeds into the station toward the rapid transit line, the station serves the function of a business office or travel agent. It is here where payment is made, tickets are purchased, travel information is supplied, and records are kept. It is important that the passenger make this transaction easily and with little time delay. Long waiting lines at ticket counters, poor and discourteous service, and lack of information will detract from the level of service. Rapid transit systems process many passengers in a short period of time, and this requires an efficient and reliable method of fare collection. The station must also act as a business office and provide the space for necessary functions to take place. These include storage areas for stock, offices for ticket agents, space for recordkeeping, and secure areas for revenue.

Beyond the fare-collection area, the passenger proceeds to the platform area where he or she will board a vehicle. At this point, the station serves as an area where passengers wait until the next vehicle arrives. If service is frequent, the passenger will wait on a platform. If service is irregular, a waiting area with seating is provided.

The services provided throughout the waiting area will also influence the user's perception of the trip. Is the area sheltered from the elements? Are other services provided, such as concessions, telephones, and restrooms? Is the station safe and well-lighted? The availability of these attributes will influence how the traveler perceives the wait.

The station also serves to communicate information to the passenger about the trip, such as his or her current location, where and when the next train will arrive, and how to get from one place to another. The station is also a communications network for management, furnishing information on such items as daily operations, schedule changes, breakdowns, emergencies, and special functions. These are handled between the control centers, the vehicles, and the station manager.

The station contains the various operations and maintenance facilities and is the location of substations, tool rooms, material storage for maintenance and facility functions, offices and workrooms, staff lunchrooms and washrooms, and offices for supervisory personnel.

In locations where the station is not at the point of origin or destination (primarily outlying stations), it must also function as the link between access modes (3). Sufficient space in the vicinity of the station must be furnished for feeder buses or trains to discharge passengers and, in suburban areas, parking near the station should be provided. The station serves as a focal point for the feeder system, and adequate provision for each arriving service must be included if the total system is to be successful. Access modes and the proportion of each will vary for each station situation, but they will include walking, bicycle, moped-motorcycle, feeder bus, automobile passengers or automobile driver (park-and-ride), and light rail feeder. The design for station access should minimize walking times and furnish a safe and convenient means of transferring from the arrival mode to the transit station.

Finally, a transit station can become an attractive location for other commercial and retail enterprises as well as high-density housing. In this role, it can serve both as a transportation center and a commercial center. Joint development of transit and commercial facilities is a logical spinoff of a successful metropolitan rapid transit system. The station can provide the spark that generates significant energy and vitality within a community.

STATION DESIGN

Passenger's Perspective

Transit user needs can be defined in terms of three factors: convenience, comfort, and safety. Each of these is discussed as it pertains to transit station design (4).

Convenience refers to the time and energy required to perform the transfer function. A convenient station is one that minimizes delay and exertion, reduces or avoids crowding, furnishes directional information, ensures service reliability, and provides customer services.

Station elements related to comfort include the provision of climate control, restroom facilities, adequate waiting areas, cleanliness, and aesthetic design. Standards have been established for environmental factors such as temperature, humidity, sound, and light. Other criteria exist for passenger flow through terminal components such as corridors, stairways, escalators, and fare gates.

Safety refers to the adequacy of police protection, emergency response to accidents, availability of emergency exits, adequate lighting, and nonskid walking surfaces. Of particular concern is passenger security against crimes. Safe conditions throughout the station should be considered in relation to walking surfaces when wet, stair details, warning signals near escalators, and adequate lighting.

A good station design is one in which each element of the station functions well with the others. When this occurs, there is a synergistic effect that produces a result with multiple benefits. For example, if the design is barrier free, it will not only help the handicapped but will ease the trip for others as well.

The single most important element in station design from the user's viewpoint is the pathway through the terminal. A simple, direct pathway reduces the need for information, improves safety and security, and provides a corridor around which consumer services can be provided. Directional information is the means by which the traveler is told where to walk in order to board the vehicle. It can be furnished by a configuration of pathways and signing. The pathway should be direct and easily recognized and should link logically with modes such as stairways and escalators.

Pathways and nodes should not be obscured, obstructed, or blocked from view by walls. Lines of sight should be clear and unobstructed. In addition to providing a clear and unmistakable path, unobstructed lines of sight will reduce the opportunity for crimes to occur. They also furnish a better opportunity for commerical development.

Directional signing should be simple to understand. Short, familiar, and consistent words should be used, and the need for translation should be avoided. Messages should be repeated when appropriate. Explicit information about the surface location of exits, transit routes, and nearby buildings should be provided, especially for underground stations. Station names should be explicit.

Service reliability within a transit station should be assured. This relates to the number of turnstiles, ticketing machines, escalators, etc. The user expects a certain amount of inconvenience, but it must be reasonable. For example, a 60-s wait for a 1-h train ride would be acceptable, whereas the same wait for a 20-s escalator ride would not be. The maintainability of equipment, the installation of heavy-duty devices, and the availability of standby equipment are essential if the station, and the system, are to operate reliably and without breakdowns. Consideration of maintenance concerns in the planning phase will enhance reliability in the long run. Consideration should be given to closing portions of stations, or possibly even the entire system, during off-peak hours in order to permit complete and thorough maintenance of the system on a regular basis.

Provision of commercial services can be a convenience to the traveler and a source of revenue for the transit authority. The type of services provided will depend on the length of time that the patron is in the terminal, the location of concessions along the pathway (they should not be placed so as to be an obstruction), and the socioeconomic characteristics of the traveler. In a rapid transit system, a large passenger volume does not guarantee commercial success, nor is the passenger a captive buyer. Careful thought should be given to the benefits and problems associated with allowing concessions in a terminal. The decision is a policy one for determination by the transit management.

The provision of climate control is well established and, once specifications are set for lighting, sound, and temperature levels, they can easily be met through design. However, the extent to which these are provided can affect passenger comfort. For example, extending covered and climate-controlled walkways to parking areas and traffic generators enhances passenger comfort. Underground pedestrian walkways that connect terminals with stores and offices have been successfully developed in many cities. Covered elevated facilities are also appropriate. These pedestrian connections enhance connectivity to destinations and create further incentives for transit use.

Cleanliness and station aesthetics are important to the functioning of the transit system. Selecting finishes that are easily maintained will help to preserve the newness of the system. Regular maintenance schedules for cleaning, disposal of trash, and removal of graffiti are one way to enhance the image of the station.

Station security is an essential requirement if other than captive riders are to be attracted to the transit system. Security can be designed into the station by providing open station and platform areas in direct view of the station attendants, direct telephone access to transit or local police, television surveillance of selected station areas, good lighting, and direct communication for passengers via telephones or alarms. Controlled spaces can be created by well-defined patterns of movement, and the station size can be reduced by using movable gates during late-evening hours when patronage is low. Vandalism can also be a serious problem, but it can be reduced in the station design process by the choice of vandalproof materials, barriers between the platform and the wall, alarms, and surveillance. The use of easy-to-clean materials and prompt removal of the signs of vandalism are deterrents to further damage of property.

Principles for designing effective passenger information systems include the following:

1. Use a single style of lettering, standard signs, and simple words.
2. Avoid advertising near information signs.
3. Locate information at critical node points where a change of direction or elevation will occur.
4. Make maps of the system and its surrounding areas available near fare-collection points and on platforms.
5. Minimize the number of independent messages.
6. Maintain continuity, consistency, and sight distances.
7. Furnish direct information that is immediately understood.

Standardization of graphics throughout the system is essential, but no standard has yet been set for graphics and signing for use in stations in different cities.

Stair design should be based on comfort and the characteristics of passenger locomotion. The trend is toward lower riser heights and wider treads; 6-in heights and 12-in treads represent a reasonable standard. Escalators are provided in most new stations and are safer and more attractive than stairs. There is the potential, however, for accidents, and care must be taken to warn pedestrians that caution must be observed when escalators are in use.

Operator's Perspective

Station operations depend on the ease with which passenger flow is accommodated at various points throughout the station. Surge volumes and heavy crowds can be handled safely and expeditiously if the station has been carefully planned (5). Among the items essential for good station operation are sufficient pedestrian exit and entrance facilities, dependable fare-collection equipment, and adequate platform dimensions. Exit and entrance facilities include wide doors, stairways, ramps, escalators, and passageways of sufficient dimension to handle large crowds. Provision should also be made to disperse patrons away from station areas to avoid crowding at street curbs and on sidewalks.

Fare-collection systems must be adequate to handle peak volumes. Long lines and crowding in mezzanine areas should be avoided. Backups should not be permitted to develop to such an extent that they interfere with passengers debarking from vehicles. Train platforms should be sufficiently adequate in size to accommodate peak flows. Objects such as stairwells, elevator shafts, utility rooms, advertising signs, and concession stands should be located so as not to impede passenger flow. Ample space should be provided to allow passengers to spread out along the platform and to uniformly fill up each train.

Station announcements should be clear and easily heard by the passengers. Directional signs should serve a useful purpose. These should be reviewed periodically to reestablish need.

Stations should be designed for each cleanup. A clean station is necessary to maintain its aesthetic value, to eliminate potential fire hazards, to avoid insurance claims, and to create goodwill. Typical of the debris found in a station are papers, sticky items on the floors and benches, and pools of liquid. Cleaning will also identify other maintenance problems. Stations should be designed to be maintained at low cost. Barriers and irregular spaces, as well as other objects that are difficult to clean, should be avoided. Good placement of trash containers is helpful.

Periodic maintenance of a station will be required over time. Damage due to occurrences such as floods, derailments, and fires may require major repair. Painting and repair of walkways, floor coverings, and roofing will be necessary from time to time. Warranties or bonds should be kept in a safe place, since replacements may be covered by a warranty. The original station design should minimize maintenance problems.

Maintenance should also be considered in the design of the station in terms of accessibility to items that will be cleaned or replaced. In the location of lighting fixtures, signs, and other similar items, consideration should be given to the fact that they must be periodically cleaned and replaced. Drainage, seepage, and water problems can be avoided by careful construction and inspection practices.

It cannot be overstressed that maintenance and operating personnel should be consulted during the planning phases of the project. These professionals will be able to review the station design in terms of how it will operate and what its potential maintenance problems will be.

EXAMPLES OF STATION DESIGN AND LESSONS LEARNED

Bay Area Rapid Transit System

The Bay Area Rapid Transit (BART) system was opened in 1972 with 26 miles of service and 12 stations. By 1974, the entire 71-mile system was opened, including 34 stations--15 subway and 19 at grade or elevated (6).

BART uses center platforms in subway stations and side platforms in suburban stations. Center platforms offer greater flexibility for loading and unloading and for differential traffic loadings and usually have higher initial costs than side platforms, although additional costs for escalators or other factors narrow this difference. A life-cycle cost analysis might show that center platforms are not as costly as side platforms. There are several station locations where center platforms might have been a better choice.

The decision to permit a variety of station designs does not appear to have posed problems or added cost. In practice, many designs are similar. Certain design criteria, such as station length, map areas, and graphics, were uniform.

Estimation of station parking did not recognize that more parking is required in outlying stations than in those close in. Although total space needs were accurate, parking areas at outlying stations are oversubscribed whereas lots closer in are not.

Provision for intermodal transfer facilities between bus and rapid transit was neglected in the planning stage. This is an important aspect of station design and should be considered early in the planning process. Bus loading areas are now being added. In addition, storage for bicycles and mopeds is being provided.

Basic circulation and orientation within the BART system are good, although a newcomer may be disoriented in locating a correct platform due to the absence of clear sight lines. A particularly vexing barrier is the stored-fare system, which is difficult to understand, time-consuming, and subject to breakdowns.

The method of fare collection is perhaps the most unique feature of the BART system and the one that creates the most difficulties within the station. Although it has many theoretical advantages in handling various fare structures, in practice it has had serious drawbacks. Aside from being complicated to operate, it is difficult to maintain. This type of equipment has not proved to be effective in situations that involve high-volume ridership on a daily basis.

Successful passenger services provided by BART include advertising, public telephones, and mailboxes. Concession stands in downtown stations have not been successful. In addition, wood benches should be removed and platform edge warnings and locker facilities for bicycles provided.

Security provisions in BART stations include good lighting, surveillance capability, courtesy telephones, and spacious areas. The need for closed-circuit television (CCTV) is evident. If this was not installed initially, the conduit work should be provided. Provisions for partial station shutdowns are needed as are barriers to fare evasion.

Washington Metropolitan Area Transit Authority

The Washington, D.C., Metro system was opened in 1976 with a 5-station line. As of 1980, the system consisted of 33.5 miles and 38 stations. When the system is complete, it will be 101 miles long and have 86 stations about equally divided between (a) subway and (b) elevated and/or at-grade. Ridership is 300 000 passengers/day (7).

Metro uses a unique station monitoring system that consists of planning staff people who review the operations of a set of stations every two weeks. They note problems and take whatever action is necessary, including follow-up on the results. This information is used in planning for future stations as well as correcting existing ones.

The planning estimates of parking spaces required fell far short of demand. Original plans called for 30 000 spaces. Revised estimates show a need for 100 000 spaces. An additional 25 000 spaces have been authorized.

Platform widths were reduced as a cost-saving measure. This has caused serious safety problems in the vicinity of escalators at the Metro Center and Farragut West stations. Again, ease of circulation for passengers was sacrificed at the expense of first cost.

Temporary terminals occur where a transit system is being built under a staged construction program. In Washington, several on-line stations are serving as temporary terminals, and this has created problems in terms of train storage, maintenance, turnback facilities, train control, accommodations for operating personnel, passenger handling and circulation, and station access. A temporary terminal may be required to serve in this capacity longer than expected, and provisions should be made in the planning stages to avoid these problems.

Attention to the problem of general maintenance should be given during the planning and design phase. Access to stationary equipment for repair and maintenance should be provided. In the Washington case, several problems of this type currently exist.

Provisions for the handicapped, including elevators, should be considered in the early phases of the project to avoid inaccessible elevator locations or elevators that must bypass fare-collection areas. The fare-collection system, which is a stored magnetic fare system similar to BART's, has been a problem. It is complicated for the public to use, it changes without notice, and it is unreliable.

Design of passenger drop-off facilities, including drop-off by taxis, is essential. At the National Airport station this was not done, and the drop-off takes place in a dangerous and illegal location.

When stations are overloaded, excess demand can create dangerous backups, queuing, and congestion. The Farragut West station is in this condition, and when the fare-collection system is not working or headways are not maintained, a dangerous and unsafe situation can occur.

In the design stage, it is necessary to ensure that adequate escalator capacity is provided in the proper location. The Metro Center station is deficient in this regard.

Bus services should be terminated at the transit station. This avoids competition between modes and provides an integrated system. Passenger drop-off facilities should be flow-through designs in order to ensure safe, efficient movement.

The Washington Metro system has selected uniform station design. Stations are well-lighted and relatively crime free. They are air-conditioned and have controlled acoustics and only minor litter or graffiti problems. They permit modest advertising and public announcements, and there are no concessions or toilets.

Metropolitan Atlanta Regional Transit Authority

The Metropolitan Atlanta Regional Transit Authority (MARTA) system was opened in 1979 with 13 stations on a 12-mile line. A north-south spine is under construction. Ridership is 85 000 passengers/day. MARTA established several design policies that affect station design (8). These policies were based on previous U.S. experience and practice in Canada and Europe:

1. The transit system is linked with the surface bus system.
2. Stations are unmanned.
3. The fare-collection system is based on a flat fare and is barrier free.
4. All stations are individually designed.

Bus loading is directly connected with station platforms. Priority is given to bus interface with separate protected roadways, minimal walking distances, good signing and graphics, and full weather protection. Bus loading is incorporated into the paid areas of stations.

Stations do not have attendants at the change booth. Security is handled at a central zone that has surveillance over 6-7 stations and is located within one of the stations. It contains CCTV monitors, security telephones, controls for fare-gates and restroom doors, and telephones for passenger assistance. It has its own security force and operates in a manner similar to the Port Authority Transit Corporation (PATCO) line (from New Jersey to Philadelphia), which controls all 13 stations from one central location.

A flat fare is used. Entry is by exact fare, and no fares are sold at the station. Entry may also be by bus-to-rail transfer or monthly fare card. There is space for token vendors. Open entry, which is used in Europe, was considered but discarded. The Atlanta experience illustrates that fare policies can have a significant effect on station design.

Uniqueness in station design, with overall control on design specifications, was adopted. This decision allowed many local architects to participate in the process. The cost apparently did not exceed that of a uniform station approach. The system does not operate between 1:00 and 5:00 a.m. Since all stations are closed during this period, station designs must include limited entrances and exists that are easily secured. Concession space was not designed into the system.

A conceptual plan was developed by staff, and the consulting firms were required to strictly adhere to it. Without this control, costs would probably have increased and exceeded budget amounts.

Temporary terminal stations are overloaded and underdesigned for interim use. These terminals will be troublesome until the next phases are complete. Stations are larger than needed, exhibiting a tendency toward monumentality in design that should be controlled. The designs for parking lots did not anticipate as many small cars as occurred. The downsizing of the American automobile is affecting parking-lot design.

MARTA claims to have adopted most of its policy from the experience of PATCO and not BART or Metro. The PATCO system, with its spartan, compact stations, illustrates that the bottom line is system reliability, access, and convenience. Since stations exist basically to transfer passengers between modes, it should do so in a safe, rapid, and smooth manner. In the downtown area, connections to major generators should be direct and use pedestrian ways. In the suburbs, emphasis must be placed on intermodal connections, adequate parking, and direct paths between access modes and the station.

TRANSIT-STATION DESIGN METHODOLOGY

A transit-station design methodology is a systematic procedure for ensuring that a station configuration fulfills its policy guidelines and objectives from the viewpoint of the transit user and the operator.

The design process begins with an inventory of data, including local site studies, travel demand, access-mode requirements, and construction costs. Policy must also be established concerning station design, operation, and maintenance. Among the items to be considered are concessions, advertising, personal-care facilities, public telephones, construction materials, fare-collection methods, intermodal integration, and provision for the elderly and the handicapped. Other aspects of station performance should be considered at this stage, including the physical environment, security, and passenger orientation.

Trial station designs can be prepared by the design team, which will consist of architects, engineers, planners, and operators. Among the considerations at this stage are adherence to policy guidelines and other considerations such as potential for joint development, station platform configuration, number of levels, location of paid and unpaid areas, and access modes.

An evaluation of the transit-station schematics is completed to compare the system costs, identify possible design problems, and determine the extent to which policy guidelines can be met. After the selection of a design concept, a series of detailed design studies can be prepared.

The design of the station will be concerned with selecting the location and amounts of various station components necessary to achieve smooth and efficient passenger processing through the station. The station designs will be evaluated in terms of travel times, queues, crossing flows, and connectivity. Transit-station simulation models, such as the Urban Mass Transportation Administration (UMTA) transit station computer simulation package, would be appropriate at this stage. Other criteria would also be considered, such as noise levels, lighting, air quality, and thermal comfort.

The candidate station designs are then evaluated in terms of cost and effectiveness. The viewpoints of the user and the operator should be considered. In some cases, there may be conflicting results to be resolved. With the selection of a station design layout and flow pattern, detailed construction drawings and specifications can be completed.

In summary, the transit-station design methodology is a planning tool for developing station configurations that take account of the specific requirements for system integration. It involves specific statements of policy concerning the role of the station, data acquisition for site selection, travel demand analysis and access mode choice, initial sketch planning, detailed design of station areas and components (e.g., parking areas, platforms, escalators, and fare collection), and the generation of alternative plans and their evaluation in terms of user and operator objectives and cost.

ACKNOWLEDGMENT

This paper is based on material presented at the National Conference on Public Transportation Terminals held in September 1980, sponsored by the Program of University Research, U.S. Department of Transportation, and conducted by the University of Virginia. The planning for the conference was done by a special subcommittee of the Intermodal Transfer Facilities Committee of the Transportation Research Board. Norman G. Paulhus was the contract monitor, and John J. Fruin chaired the planning committee.

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

Guidelines for Allocating Public Transportation Costs Among Towns in Nonurbanized Areas

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A crucial question affecting the long-term viability of public transportation programs in nonurbanized areas concerns the allocation of deficit costs among towns receiving service. An evaluation is presented of alternative cost-allocation procedures that include one or more of the following variables: population, property valuation, passenger trips, passenger miles, vehicles miles, and vehicle hours. The procedures are evaluated based on several criteria, including simplicity, data requirements, cost of use, and equity (or perceived fairness) of the allocations. The evaluation brings into perspective the need to make trade-offs among these criteria. Sensitivity analysis is therefore conducted to determine the relative differences in allocations depending on (a) the procedure, (b) the data sampling method, and (c) the cost assignment policy. Population, ridership, and cost data on two public transportation programs in nonurbanized areas of Massachusetts are used to conduct the evaluation. One service, operated in Barnstable County, is offered on a prearranged demand-responsive basis. The other provides fixed-route, fixed-schedule service to nine towns in Franklin County.

Recent government actions have responded to the need for public transportation programs in nonurbanized areas (1-4). Starting with the Federal-Aid Highway Act of 1973 (Section 147) and continuing with the Urban Mass Transportation Act of 1964 as amended (Section 18), increasing amounts of federal aid have been committed to support these programs. Many states have supplemented this federal aid with financial assistance of their own. In many cases, local governments are financially responsible for as much as 25 percent of the deficit costs of such programs.

A crucial question affecting the long-term viability of these programs concerns the allocation of deficit costs among towns receiving service. Many communities desire precise information on the manner in which deficit costs will be allocated before deciding to participate in such programs. At the same time, these towns lack the resources to carry out adequate cost-allocation analyses themselves.

The purpose of this paper is to present a critical evaluation of cost-allocation procedures available for use in nonurbanized areas. The procedures discussed are applicable to fixed-route and demand-responsive systems and may be pertinent to urban transportation programs as well. Twelve selected procedures are applied by using population, ridership, and cost data on two public transportation programs in nonurbanized areas of Massachusetts (Franklin and Barnstable Counties). Both programs were initiated several years ago under the Federal Highway Administration (FHWA) Section 147 Demonstration Program and are currently being supported with federal Section 18 funds and state and local resources.

Based on the results of this evaluation, conclusions about the overall usefulness of the various procedures are presented. The paper is intended to serve as a guide for regional and local transportation officials who are considering the implementation of public transportation programs in their nonurbanized areas.

DEFINITION OF TERMS

Before we proceed, some clarification is in order regarding the definition of certain terms. For the purposes of this paper, a cost-allocation procedure is a means of determining what portion of the local share of the deficit each town should pay. A procedure consists of an equation or formula that determines town allocations based on one or more variables. Depending on the procedure favored by regional and local officials, variables can represent the level of service available to each town, the amount of service actually used by each town, or a town's ability to pay.

The total costs of public transportation services may be broken down into capital costs (e.g., purchase of vehicles and other equipment) and operating costs (e.g., driver's wages, fuel, and oil). These total costs can be annualized (i.e., expressed on an annual basis). The difference between the total annual costs and total annual revenue is the annual deficit costs (assuming that costs exceed revenues).

BASIC ISSUES IN COST ALLOCATION AMONG TOWNS

Many different cost-allocation procedures are available for use by regional transportation agencies in nonurbanized areas (5). The various procedures differ in their variables. The most common procedures use one or more of the following variables: population, property valuation, passenger trips, passenger miles, vehicle miles, or vehicle hours. In cases where a multivariable procedure is used, weights can be assigned so that one factor is counted more heavily than another. The choice of variables or weighting schemes depends on a number of criteria, such as simplicity, data requirements, cost to use, and equity of results. Each criterion must be balanced against another to produce a procedure that is acceptable to a particular region. A discussion of these criteria can provide the context within which the comparative evaluation of procedures can be carried out. For discussion purposes, the criteria have been grouped into two categories: (a) ease and cost of implementation and (b) equity. The implementation criteria relate to the ease and cost with which procedures can be used. Equity criteria relate to the ability of the procedures to produce results that are considered fair by the member towns.

Ease and Cost of Implementation

One consideration in choosing a cost-allocation procedure is the ease with which it can be implemented and understood by the public. Included in this category are the criteria of simplicity, data requirements, and costs of implementation. All are wed to the notion that a procedure that is simple, requires little collection of new data, does not require a computer, and costs little to implement will have an easier time gaining acceptance from transit authority members and the public at large. Examples of such simple procedures are single-variable formulas based on general population, elderly population, and/or real estate valuation.

The advantage of these procedures is that they are based on information that is readily available to the public. No new data collection is required, which reduces the costs and the time required for implementation. Because no complex formulas are used, the procedures can be readily understood by the public. On the negative side, the simplest procedures often bear no relation to the relative level of services provided or to the operating costs incurred in service to each town. Consequently, procedures based on a single variable, the level of service provided to each town, may be considered as an answer to the above concern. Although these procedures are in general easy to understand, the data regarding the level of service to each town may not be as readily available as population or real estate valuation.

Multivariable procedures are more complex, as indicated by both the number of variables included and the process required to derive the necessary data for implementing the procedure. As a result, multivariable procedures are usually adopted for implementation only when local officials have multiple views regarding the basis on which cost allocations should be made.

The cost and the time required for implementing these procedures are usually less for the single-variable procedures than for the multivariable ones. The cost and time required for implementation can be expected to increase as the complexity of the procedure increases.

Equity

As mentioned previously, procedures for allocating transportation costs are designed to satisfy the criterion of equity, among others, as determined by the towns receiving service. However, care must be taken in defining the term equity, since its perception may differ from one town to the next. Whereas one town may argue that for a procedure to be deemed "equitable" it must incorporate measures of the level of service available and/or the amount of service used, these principles may be rejected by another town. It is therefore safe to state that, due to possible different interpretations of what is equitable, no single cost-allocation procedure may be deemed "correct" or equitable in all circumstances. In the final analysis, the most equitable procedures will be those that are economically and politically acceptable to all participants.

It is pertinent to note that procedures that seek to satisfy equity concerns may occasionally achieve their "fair" results at the expense of the implementation factors just discussed. This is particularly so if the attempt is to reflect several aspects of the transportation service in the procedure to be implemented. In addition, due to the sensitivity of the complex equitable formula to changes in the values of the variables included, data on level of service and use must be continuously updated. This increases the cost of maintaining the fairness of the results obtainable from a complex procedure.

Finally, it is worth noting that the criteria of simplicity, cost, and equity are not mutually exclusive. It is entirely possible to create a formula that combines variables that satisfy, to a certain extent, the demands of all three criteria. For instance, a formula could be developed that measures the quantity of service available to a particular town and also considers the relative population of that town. In such a case, weights could be assigned to the variables so that one measure would count more than the other within the procedure.

It has been found (5) that the ultimate goal of most regional transit authorities in designing a cost-allocation procedure is to find the optimum balance between ease and cost of implementation and fairness of results. Where that optimum point is located depends largely on the specific desires of the towns that make up the region.

EVALUATION OF ALTERNATIVE PROCEDURES

An evaluation of alternative procedures to allocate costs among towns is presented below. Population, ridership, and cost data from two nonurbanized areas are used to evaluate 12 procedures as they relate to the criteria of ease and cost of use and fairness of results as well as to overall economic and political acceptability.

In Barnstable County, the Cape Cod Regional Transit Authority (CCRTA) provides advance-reservation, demand-responsive service to the general public in 15 towns (total population 126 481). The Franklin Regional Transit Authority (FRTA) operates fixed-route, fixed-schedule service to 9 towns (total population 15 562).

Barnstable County: Demand-Responsive Service

Selection and Use of Current Procedure

The overriding objective of CCRTA members in selecting a cost-allocation procedure was to adopt a "pay for what you get" approach. Simple, low-cost procedures based on population were rejected because they did not consider the relative quantity of services received by participating towns. One factor in the decision to adopt a use-based procedure was the current existence of rider identification passes, which made it easy to collect passenger data. This informtion, which was being collected, keypunched, and processed for monitoring and evaluation purposes, could be used to determine town-by-town levels of use at little extra cost to CCRTA.

In determining how to measure levels of use for cost-allocation purposes, CCRTA decided that trip length should be incorporated into the procedure along with trip volume. Trip volume alone, although easier to measure, was not viewed as an adequate indicator of use due to the extreme variability in trip length. The average trip length for town residents had been shown to range from 5.1 miles (Barnstable) to 21.2 miles (Bourne). This variability is caused by the elongated nature of the service area and the fact that many of the trips, regardless of origin, terminate in Hyannis, a major activity center. It was believed that many of the major costs of providing the service varied proportionately with trip length rather than being associated with trip volume.

Description of Procedure

CCRTA instituted a two-variable procedure based on passenger trips (trip volume) and passenger miles

Table 1. Comparative assessments based on alternative procedures: CCRTA demand-responsive service.

Town	Population		Elderly Population		Property Valuation		Passenger Trips and Passenger Miles		Elderly Population, Valuation, Passenger Trips and Miles	
	Amount ($)	Percent	Amount ($)	Percent	Amount ($)	Percent	Amount ($)	Percent	Amount ($)	Percent
Barnstable	8 776	17.6	7 270	14.5	7 110	14.2	9 204	18.4	7 412	14.8
Bourne	6 223	12.4	2 735	5.5	3 290	6.6	2 415	4.8	2 734	5.5
Brewster	8 899	1.8	1 533	3.1	1 811	3.6	835	1.7	1 948	3.9
Chatham	3 349	6.7	4 221	8.4	4 856	9.7	912	1.8	3 198	6.4
Dennis	2 059	4.1	4 279	8.6	3 882	7.8	5 185	10.4	4 184	8.4
Eastham	1 367	2.7	1 684	3.4	2 080	4.2	478	1.0	1 361	2.7
Falmouth	9 787	19.6	7 091	14.2	6 536	13.0	9 311	18.6	7 329	14.7
Harwich	3 787	7.6	6 562	13.1	3 629	7.2	2 908	5.8	5 873	11.7
Mashpee	602	1.2	126	0.3	1 553	3.1	3 095	6.2	1 565	3.1
Orleans	848	1.7	1 957	3.9	2 512	5.0	2 340	4.7	2 164	4.3
Provincetown	1 202	2.4	885	1.8	576	1.2	5 787	11.5	2 313	4.6
Sandwich	3 612	7.2	1 630	3.3	5 317	10.6	2 485	5.0	3 091	6.2
Truro	417	0.8	100	0.2	1 130	2.3	165	0.3	432	0.9
Wellfleet	957	1.9	560	1.1	2 384	4.8	1 428	2.9	1 431	2.9
Yarmouth	6 117	12.3	9 367	18.7	3 342	6.7	3 466	6.9	4 969	9.9
Total	58 002		50 000		50 008		50 014		50 004	

(trip length). These two use variables are weighted to reflect the different costs associated with each. The costs of dispatching and administrative costs were assigned to passenger trips, and all other operating costs were assigned to passenger miles. The ratios of these costs to total operating costs are coefficients that are used to obtain systemwide unit costs per trip and per passenger mile. A unit cost is calculated for each use variable. These unit costs are multiplied by each town's respective number of trips and miles, and the products are added to obtain a total allocation for each town. Town revenues, derived from data on pass sales, are then subtracted to obtain a net local allocation.

The procedure can be illustrated by delineating the assignment of costs to each of the two variables, as follows:

1. Passenger miles (approximately 75 percent)--Drivers, fuel, repairs, insurance, advertising and promotion, and special equipment; and
2. Passenger trips (approximately 25 percent)--Dispatching, office expenses, and monitoring and evaluation.

The coefficients for passenger miles and passenger trips are 0.75 and 0.25, respectively, which means that three-quarters of the system's costs relates to vehicle operations and one-quarter relates to dispatching and administration. The formula for calculating assessments can thus be shown as follows:

$$D_A = 0.25[0.75(OC)(M_A/M_T) + 0.25(OC)(T_A/T_T) - R_A] \quad (1)$$

where

D_A = deficit to be paid by town A,
OC = total operating costs,
M_A = passenger miles for residents of town A,
M_T = passenger miles for residents of all towns,
T_A = passenger trips for residents of town A,
T_T = passenger trips for residents of all towns, and
R_A = revenues generated by town A.

This procedure was examined by CCRTA using 1978 data, in preparation for eventual implementation, after the termination of the Section 147 grant. The procedure has been in use officially since February 1979. The resulting assessments have been accepted generally by member towns as being equitable, although some concern has been expressed that the 75/25 allocation of costs to the two variables results in a penalty being imposed on peripheral towns whose average trip length is high. Representatives of these towns have expressed the opinion that the initial assignment of costs to the categories of passenger trips and passenger miles was to some extent arbitrary and contended specifically that all costs except drivers, fuel, and repairs are of a fixed nature and should be assigned to passenger trips. This type of alteration would change the weighting from 75/25 to 50/50 and, consequently, could lessen the burden on towns that have relatively high average trip lengths.

Comparative Evaluation of Procedure

This evaluation compares the CCRTA cost-assessment procedure with four alternative procedures that have been suggested for use in other demand-responsive systems. The alternative procedures differ in terms of their ease and cost of application and their ability to produce results that all parties consider fair.

Table 1 compares the allocations produced by the five tested procedures. It is worth noting the widespread variation in results. Of greatest significance is the discrepancy between allocations produced by the single-variable, non-use-based procedures (population and property valuation) and the use-based CCRTA procedure (passenger trips and miles). The differences between population and passenger use are clearly evident in towns such as Bourne, Chatham, Eastham, Mashpee, Orleans, and Provincetown, where allocations under the two procedures vary as much as fivefold.

Differences also exist between elderly population and passenger use. Mashpee's allocation increases 24 times, from $126 to $3095, when passenger use replaces elderly population as the basis for assessment. It is also significant to note that elderly population and general population do not show a close comparison.

Property valuation produces significantly different allocations when compared with passenger trips and miles. As an example, Chatham's valuation-based allocation is 5 times greater than its use-based allocation; conversely, Provincetown is allocated 10 times more under passenger use than under valuation. If "ability to pay" were to be the overriding criterion for choosing a procedure, the valuation-based allocations might be acceptable. If

Table 2. Summary of data: CCRTA demand-responsive service.

Town	Population		Elderly Population		Property Valuation		Passenger Trips		Passenger Miles		Revenue	
	No.	Percent	No.	Percent	Amount ($000 000s)	Percent	No.	Percent	No.	Percent	Amount ($)	Percent
Barnstable	26 699	21.1	6 362	19.2	926.3	19.0	12 059	32.1	61 368	18.2	7 952	27.2
Bourne	11 262	9.0	1 524	4.6	257.8	5.3	782	2.1	16 561	4.9	919	3.1
Brewster	3 709	2.9	1 226	3.7	197.6	4.1	1 078	2.9	9 471	2.8	1 400	4.8
Chatham	6 027	4.8	1 955	5.9	324.7	6.7	370	0.1	6 666	2.0	456	1.6
Dennis	9 351	7.4	3 380	10.2	471.0	9.7	3 229	8.6	41 426	12.2	3 808	13.0
Eastham	3 069	2.4	928	2.8	163.3	3.3	723	1.9	3 595	1.1	536	1.8
Falmouth	20 648	16.3	4 275	12.9	596.0	12.2	4 129	11.0	58 356	17.3	3 136	10.7
Harwich	7 786	6.2	3 214	9.7	292.8	6.0	1 336	3.5	18 929	5.6	1 128	3.8
Mashpee	2 496	2.0	464	1.4	154.1	3.2	1 356	3.6	19 113	5.6	984	3.4
Orleans	4 369	3.4	1 591	4.8	266.1	5.5	2 597	6.9	16 022	4.7	1 848	6.3
Provincetown	3 947	4.1	895	2.7	113.8	2.3	3 726	9.9	28 916	8.5	1 256	4.3
Sandwich	6 358	5.0	828	2.5	349.0	7.2	975	2.6	13 200	3.4	352	1.2
Truro	1 260	1.0	199	0.6	94.1	1.9	153	0.4	2 615	0.8	367	1.3
Wellfleet	1 973	1.6	365	1.1	168.1	3.4	612	1.6	8 054	2.4	312	1.1
Yarmouth	17 427	13.8	5 932	17.9	503.6	10.3	4 469	11.9	33 723	10.0	4 824	16.5
Total	126 381		33 138		4878.3		37 594		338 015		29 271	

Table 3. Impacts of different assignments of costs to variables.

Town	75/25 Ratio		50/50 Ratio	
	Amount ($)	Percent	Amount ($)	Percent
Barnstable	10 938	20.9	12 860	24.5
Bourne	2 278	4.3	1 889	3.6
Brewster	1 334	2.4	1 343	2.6
Chatham	917	1.7	780	1.5
Dennis	5 822	11.1	5 317	10.1
Eastham	630	1.2	748	1.4
Falmouth	8 592	16.4	7 726	14.7
Harwich	2 758	5.3	2 476	4.7
Mashpee	2 826	5.4	2 544	4.9
Orleans	2 694	5.1	2 993	6.7
Provincetown	4 999	9.5	5 187	9.9
Sandwich	2 049	3.9	1 868	3.6
Truro	313	0.6	263	0.5
Wellfleet	1 233	2.4	1 129	2.2
Yarmouth	5 040	9.6	5 304	10.1
Total	52 423		52 427	

Table 4. Impacts of sampling methods.

Town	12-Month Data		3-Month Data		1-Month Data	
	Amount ($)	Percent	Amount ($)	Percent	Amount ($)	Percent
Barnstable	10 938	20.9	10 322	19.7	9 940	19.0
Bourne	2 278	4.3	2 472	4.7	2 843	5.4
Brewster	1 334	2.5	966	1.8	909	1.7
Chatham	917	1.7	824	1.6	633	1.2
Dennis	5 822	11.1	6 504	12.4	6 984	13.3
Eastham	630	1.2	642	1.2	848	1.6
Falmouth	8 592	16.4	8 447	16.1	7 979	16.2
Harwich	2 758	5.3	3 322	6.3	3 443	6.6
Mashpee	2 826	5.4	3 615	6.9	3 924	7.6
Orleans	2 694	5.1	2 504	4.8	2 576	4.9
Provincetown	4 999	9.5	3 127	6.0	2 832	5.4
Sandwich	2 049	3.9	2 459	4.9	2 304	4.4
Truro	313	0.6	535	1.0	1 046	2.0
Wellfleet	1 233	2.4	1 204	2.3	881	1.7
Yarmouth	5 040	9.6	5 466	10.4	5 282	10.1
Total	52 423		52 409		52 424	

the desire of member towns is to pay in proportion to the service they receive, a valuation-based procedure is likely to raise considerable opposition.

The allocations that result from the application of the comprehensive, three-variable procedure are also significantly different from those based on the CCRTA procedure. In general, however, the allocations fall in between those that result from the individual use of elderly population, valuation, or passenger use. It appears that a comprehensive formula has the ability to moderate the extreme effect of any one variable on a town.

To test the impact of using different methods of assigning costs, a sensitivity analysis was undertaken. As indicated earlier, several towns in the outlying area of Barnstable County have contended that the method that yields the 75/25 ratio imposes an unfair burden on them because their residents make fewer trips than do residents in towns near the center of the county. The differences between passenger trips and passenger miles in the towns can be seen in Table 2, where Barnstable, a "core" town, is shown to have three times as many passenger trips as Falmouth, a "peripheral" town. Passenger miles for the two towns, however, are almost equal. In the analysis, allocations were estimated with a 50/50 ratio and compared with the allocations that used a 75/25 ratio. The results, as given in Table 3, reveal that, with the exception of the two major towns in the region, differences are minor. Barnstable's allocation is significantly higher where trips and miles are weighted equally, and Falmouth's share is somewhat lower under the same scheme. All other towns' allocations differ by less than one percentage point.

Finally, an analysis of the impact of data-sampling methods on the allocations was performed. The high cost of collecting and processing 100 percent data has led CCRTA to examine the viability of data sampling. In order to address this concern, allocations based on the full 12 months' data were compared with those based on 1 and 3 months' data. The sample time periods selected for the analysis were found to be most representative of the 12-month totals, based on aggregate monthly ridership statistics. The results of the analysis can be seen in Table 4. Differences between the 3-month and 12-month figures are generally insignificant, although there appears to be a slightly greater disparity between the 1- and 12-month figures, particularly in the cases of Mashpee, Provincetown, and Truro. The overall significance of these differences negating the viability of the sampling techniques must be weighted against the lower costs for data collection and processing. It should be noted that data-sampling techniques constitute one means of improving the efficiency and reducing the costs of data collection and processing. Other means, such as the use of a minicomputer, are also being considered by CCRTA.

Major Findings

Based on the Barnstable County data for 1978, alternative procedures for allocating public transportation costs among towns produce significantly different allocations.

Single-variable procedures (population, elderly population, and property valuation) tend to promote extreme results that bear little relation to passenger use. If simplicity and cost-of-use criteria are of overriding importance, such procedures may be acceptable. If "paying for services received" is the main criterion, such procedures are clearly unacceptable.

Comprehensive procedures that include population and ridership variables have the advantage of addressing a broader set of concerns in relation to cost allocation. Such procedures also tend to moderate the extreme effects of individual variables on towns.

The two-variable CCRTA procedure provides an adequate reflection of services received by member towns. The weighting of the two variables can significantly affect assessments for some of the towns.

The sole drawback to the CCRTA procedure is the cost of its use, which results from high data requirements. To mitigate that limitation, CCRTA is exploring several cost-reduction mechanisms, including data-sampling methods and the use of a minicomputer for data collection and processing. The use of data samples does not appear to significantly affect allocations, although care must be taken in selecting time periods where ridership is most representative of the full 12-month period.

Franklin County: Fixed-Route, Fixed-Schedule Service

Selection and Use of Current Procedure

During the fall of 1979, the members of FRTA adopted a cost-assessment procedure that was significantly more complex in nature than those adopted by other regional transportation authorities (RTAs) in New England. This complexity reflects a high degree of concern on the part of FRTA members that allocations be considered equitable by all parties.

This concern was particularly evident in the case of two adjacent towns, Shelburne and Buckland, which are linked by the village of Shelburne Falls, a major stop along one of the three FRTA routes. Shelburne is particularly sensitive to the possibility of being overassessed in relation to Buckland, if the only component in the cost-allocation procedure is a vehicle-hours or vehicle-miles variable. Vehicle hours and miles accrue almost entirely to Shelburne; consequently, costs incurred by the transit operator are much greater in that town than in Buckland. However, it is generally perceived that ridership for the two towns is reasonably similar. This has created a delicate political situation and has served as the main catalyst behind the formation of a procedure that is comprehensive enough to negate inequities associated with individual variables.

Although this is one example of an important issue that had to be dealt with in the formation of the procedure, other factors were considered by transit officials to be of significance. These can be summarized as follows:

1. Population, either by itself or in combination with other variables, is related neither to ridership nor to service availability and should not be part of the cost-allocation procedure.
2. Passenger use is an important consideration and should be incorporated into the procedure.
3. Because trip length tends to be disproportionately high in rural areas, time-based variables (e.g., vehicle hours) are considered to be more equitable than distance-based variables (e.g., vehicle miles).

Description of Procedure

The procedure adopted by towns receiving fixed-route service uses three variables, each weighted equally. The variables are (a) vehicle hours, (b) vehicle trips, and (c) number of passengers. Each town's proportion of systemwide totals is determined separately for the three variables. An average of the three ratios is obtained, and this is then multiplied by systemwide gross operating costs to determine "gross costs incurred" in each town. Town revenues, obtained from sample data, are then subtracted from this figure to obtain "net costs incurred". This figure is multiplied by 0.25 (local share under Section 18) to obtain the town's share of the operating deficit.

The procedure can be illustrated through the following formula:

$$D_A = 0.25 \left\{GC_T[(VH_A/VH_T) + (VT_A/VT_T) + (P_A/P_T)]/3 - R_A \qquad (2)$$

where

D_A = deficit share for town A,
GC_T = gross operating costs systemwide,
VH_A = vehicle hours for town A,
VH_T = vehicle hours systemwide,
VT_A = vehicle trips for town A,
VT_T = vehicle trips systemwide,
P_A = passengers for town A,
P_T = passengers systemwide, and
R_A = revenue for town A.

The local share of FRTA's administrative costs is assessed according to the town's proportion of the total operating deficit.

Data-Collection and Processing Methods

Because FRTA provides fixed-route, fixed-schedule service, many of the required data (vehicle hours and vehicle trips) can be obtained from the route schedule. Only passenger and revenue data must be obtained on-board. FRTA intends to conduct periodic sample surveys to obtain such information.

The cost of data collection and processing essentially equals the cost of the on-board sample surveys, plus the cost of manually tabulating the statistics. Because the schedule is fixed, the data are tabulated only once, and slight alterations are made for month-to-month variations. Separate calculations are required only when new or seasonal schedules are put into effect. Since a summer schedule was in effect for part of the July through September period studied in this analysis, two tabulations were needed. Each tabulation required approximately 20-30 person-hours of time.

Comparative Evaluation of Procedures

The evaluation of the three-variable formula currently used by FRTA could not be included in this data analysis because of the lack of data regarding the third variable, passenger use. As a result, only the alternative procedures are tested with real data. The concluding statements do, however, include some general comments about the FRTA procedure.

The data used for the analysis cover the first quarter of fiscal year 1980. Allocations made from the full three months' data are compared with allo-

Table 5. Comparative local assessments based on alternative procedures: three-month and one-month data for FRTA fixed-route service.

	Population		Vehicle Miles		Vehicle Hours		Vehicle Miles and Vehicle Hours		Population, Vehicle Miles, and Vehicle Hours	
Town	Amount ($)	Percent	Amount ($)	Percent	Amount ($)	Percent	Amount ($)	Percent	Amount ($)	Percent
3-Month Data										
Bernardston	293	5.2	437	7.6	406	7.2	414	7.4	401	7.1
Buckland	947	16.8	0[a]	0.0	184	3.3	104	1.8	192	3.4
Charlemont	399	7.1	987	17.2	832	14.8	871	15.5	822	14.6
Colrain	776	13.8	302	5.3	436	7.8	403	7.2	442	7.9
Deerfield	615	10.9	1997	34.8	1203	21.4	1401	24.9	1319	23.5
Gill	692	12.3	73	1.3	84	1.5	81	1.4	145	2.6
Northfield	1075	19.1	323	5.6	941	16.7	787	14.0	817	14.5
Shelburne	719	12.8	1492	26.0	1369	24.3	1400	24.9	1329	23.6
Rowe	111	2.0	132	2.3	173	3.1	162	2.9	157	2.8
Total	5627		5743[b]		5628		5623		5624	
1-Month Data										
Bernardston	293	5.2	437	7.6	437	7.7	437	7.8	422	7.5
Buckland	947	16.8	0[c]	0.0	174	3.1	96	1.7	185	3.3
Charlemont	399	7.1	987	17.2	853	15.2	886	15.8	835	14.9
Colrain	776	13.3	292	5.1	385	6.9	362	6.4	405	7.2
Deerfield	615	10.9	2182	37.9	1368	24.3	1571	28.0	1472	26.2
Gill	692	12.3	42	0.7	42	0.7	42	0.7	110	1.9
Northfield	1075	19.1	323	5.6	983	17.5	818	14.6	844	15.0
Shelburne	719	12.8	1441	25.0	1338	23.8	1313	24.3	1296	23.1
Rowe	111	2.0	49	0.9	39	0.7	41	0.7	49	0.9
Total	5627		5753[d]		5619		5616		5618	

[a]-$136. [b]$5607. [c]-$36. [d]$5517.

cations made from a one-month data sample. As in the previous analyses of Barnstable data, the examination of data-sampling methods is an integral part of the evaluation.

The following discussion begins with the assumptions under which each data analysis was carried out, briefly describes and analyzes the alternative procedures, and concludes with the comparative evaluation. Allocations based on these data are given in Table 5.

In a comparison of the allocations produced by the five alternative procedures for the three-month period, several noteworthy factors stand out. First, most of the procedures yield significantly different allocations. This dissimilarity is particularly noticeable among the single-variable procedures, where the use of population produces assessments that differ as much as ninefold from the level of service-based procedures (vehicle miles and hours). Buckland, Colrain, and Gill are relatively overassessed when population is used, whereas Charlemont, Deerfield, and Shelburne are relatively underassessed. Based on these widely varying assessments, it is difficult to envision the use of any one of these single-variable procedures without significant opposition from certain towns.

A closer examination of the single-variable (vehicle-miles- or vehicle-hours-based) procedures reveals substantial evidence of a lack of correlation between the allocations, particularly in regard to Northfield and Deerfield. Note, for instance, the negative assessment that Buckland receives under the vehicle-miles-based procedure. This anomaly is the result of the revenue (6.6 percent of total) being much greater than the cost attributed to vehicle miles (1.7 percent of total). It clearly portrays the importance of analyzing route design and other site-specific geographic and service features before a decision is made on the use of a procedure. In regard to the contention that a vehicle-miles-based procedure penalizes outlying towns and a vehicle-hours-based procedure penalizes core towns, no significant conclusions can be drawn from this analysis. Since the only undisputed core town in the region, Greenfield, is not included in the analysis, any potential findings are inconclusive.

The two multivariable procedures result in allocations that are less extreme than those that result from the single-variable procedures. Differences between the two procedures are generally minor. The towns with the lowest levels of service (Buckland and Gill) have somewhat higher allocations from the three-variable procedure, where the population variable is introduced, whereas allocations for the towns with the highest levels of service (Deerfield and Shelburne) decrease slightly.

In comparing allocations based on the full three months' data with those based on the one-month sample (Table 5), significant differences are generally found only in those towns that were affected by the transition from the summer to fall schedule. The month chosen for the sample was July, when the full summer schedule was in effect. The town of Rowe, for example, received only Saturday service during the summer. Under the "hours-miles" procedure, the allocation for Rowe for the month of July amounted to 0.7 percent of the total deficit. The town started receiving daily service after September 17, which was enough to raise its three-month share of the deficit (2.9 percent) to four times its one-month share. It appears, then, that sampling is a valid technique in a fixed-route, fixed-schedule service but that data samples must take into account different schedules that may be in effect during the course of a year.

It must be recognized that sampling does not have the same implications for a fixed-route system as it does for a demand-responsive system. In the latter, costs of collecting and processing passenger-use data can be high and significant savings can be realized from sampling. In a fixed-route system, however, such costs are minor to start with, which reduces the potential impact and overall level of importance of sampling. If sampling is used, it appears that the only variables that are likely to change over time are passenger use and revenue. This analysis has shown the sensitivity of allocations to a variable such as revenue and in the process pointed out that a one-day data sample may not be sufficient or valid.

Table 6. Summary of cost-allocation procedures.

Type of Operation	Variable	Equity Implications of Variable	Ease of Understanding	Data Requirements	Cost of Use	Computer Needed
Demand-responsive	Population	Service availability	High	Low	Low	No
	Elderly population	Service availability	High	Low	Low	No
	Property valuation	Ability to pay	High	Low	Low	No
	Passenger miles	Use levels	Medium	Medium-high	Medium	Yes
	Passenger trips	Use levels	Medium	Medium	Low-medium	No
	Population, property valuation, passenger trips and miles	Service availability, ability to pay, use	Low	High	High	Yes
	Passenger trips and miles	Use levels	Low-medium	High	High	Yes
Fixed-route	Population	Service availability	High	Low	Low	No
	Vehicle miles	Service availability	Medium-high	Low-medium	Low-medium	No
	Vehicle hours	Service availability	Medium-high	Low-medium	Low-medium	No
	Vehicle miles and hours	Service availability	Low-medium	Medium	Medium	No
	Population, vehicle miles and hours	Service availability	Low-medium	Medium	Medium	No

Finally, some mention should be made of the absence of passenger-use variables (e.g., passenger trips) in this analysis and what effect that absence may have on the alternative allocations. Because revenues are being applied to the towns and passenger use is not, towns are being rewarded for their use of the system. If the underlying objective of the towns is to pay for what they get, these procedures do not achieve that objective. Buckland's "negative assessment" under the vehicle-miles-based procedure is a clear example of what can result when revenue, but not passenger use, is considered.

Major Findings

In the case of FRTA, the tested procedures yield widely varying assessments, partly due to unique service and geographic characteristics.

Single-variable procedures (population, vehicle miles, and vehicle hours) produce particularly extreme assessments. Conversely, multivariable procedures tend to moderate the extreme effect of individual variables and promote results that are more balanced.

There appears to be a very weak relation between townwide population and either of the two vehicle-based variables. If population is to be used in a fixed-route procedure, one suggestion might be to include only those people living within a reasonable distance of the routes.

A clear advantage of the three-variable FRTA procedure over the procedures that were tested is its consideration of passenger use. If, as in the case of the five tested alternatives, revenues are credited to towns but passenger use is not, towns are rewarded for using the system.

The issue of data sampling is not pertinent to this analysis because data-collection and processing costs are low to start with. Vehicle data must, however, reflect seasonal schedule changes.

SUMMARY

The study described in this paper has evaluated a variety of procedures for allocating public transportation costs among towns and discussed their applicability to various types of public transportation programs in nonurbanized areas. These procedures are summarized in Table 6. It is intended that the information presented in this table, together with the specific findings of the evaluation, will serve as a guide to public transportation officials who may be in the process of selecting a procedure.

CONCLUSIONS

Based on evaluation, a number of general conclusions can be made about the usefulness of the various types of cost-allocation procedures:

1. Single-variable procedures, such as those based on population and ability to pay, clearly are the easiest to understand and least costly to use. However, they are not likely to meet expectations of fairness, if fairness is to be equated with relative quantity of services available or used.
2. Multivariable procedures have the ability to combine and weight potentially conflicting perspectives and cost-allocation philosophies, thus providing the decision maker with an added degree of flexibility. They also tend to moderate inequities that may arise from the use of any one variable.
3. Procedures based on passenger miles and/or passenger trips have the advantage of being able to relate cost allocations to the amount of service consumed or used by each town. Such procedures may be relatively expensive to use, but this drawback can be mitigated through the use of alternative data-collection methods or data-sampling techniques.
4. The review of the current procedures being used in Franklin and Barnstable Counties shows a clear preference on the part of transit officials for procedures that are based on availability and/or use levels. Although simplicity and cost-of-use factors are of considerable concern, the overriding desire of the officials and the towns they represent is to base allocations on the amount of services received.
5. Procedures that incorporate passenger-use variables (e.g., passenger miles) are more suitable for demand-responsive systems, whereas those that incorporate level-of-service variables (e.g., vehicle miles) are more suitable for fixed-route systems. This distinction, although not rigid, is due to the difference in data-collection and processing methods appropriate to the two types of service. However, the use of certain procedures can help a transit authority to achieve other service-related objectives. For instance, procedures based on vehicle miles serve to encourage group ridership in a demand-responsive system. Ridesharing can result in more service to a town at less cost, but, more importantly, it can lead to more efficient vehicle use and higher system productivity.

It is important to reiterate that there is no single procedure that is ideal for any particular transportation program. The variety of procedures identified in this study all correspond to different sets of philosophies and personal values concerning equity. In addition, site-specific political and financial considerations play an ever-increasing role in the determination of an appropriate procedure.

The decision-making process for choosing among alternative procedures does appear to follow somewhat standard lines, despite the importance of highly variable local political factors. The goals of maximizing fairness and minimizing complexity and cost of use appear to be shared by most public officials. As mentioned earlier, the satisfaction of these objectives presents a potential conflict for the decision maker, whose role it is to find the appropriate trade-off point between the two goal orientations. On the one hand, the procedure must be understandable to the public and not overly difficult or expensive to use. On the other hand, it must be comprehensive enough to satisfy the numerous demands for fairness made by the towns in the service area. It appears that the fairness objective tends to be dominant in the perspective of most decision makers. Simplicity may be of overriding importance when the system is new or when the number of participants is small, but as the service grows in scope equity becomes increasingly significant. It is particularly important when the system is trying to extend services to new communities. The willingness of a town to join an RTA and receive service often hinges on the perception that its future financial obligation will be fair and equitable.

Regardless of which approach is taken and which procedure is ultimately selected, it is clear that cost allocation is playing a more important role in the development of comprehensive, coordinated rural public transportation systems and will play an even larger role in the future. With a continuation of federal operating assistance expected in the future (a proposed $420 million for the Section 18 program through fiscal year 1985), there will be ample opportunity for regions to initiate new programs or expand existing ones. In many cases, the only barrier to successful implementation will be the lack of local political and financial support. Without this support, the region may have to settle for a very basic system or no system at all. A cost-allocation procedure that is acceptable to all the towns in the region can help bring about the necessary political support and thereby reduce uncertainty over financial commitment. In doing so, it can help achieve the major goal of providing a public transportation service to those who need it.

ACKNOWLEDGMENT

This work was sponsored by the Office of University Research, U.S. Department of Transportation. The assistance and guidance of project monitors Raymond Benacquista and Douglas McKelvey of FHWA are gratefully acknowledged. Special thanks to Robert P. Warren and Anthony Rogers of CCRTA and Peter Stoddard and Cindy Dewey of FRTA.

The opinions and conclusions expressed or implied in this paper are ours and not those of the research agency.

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Publication of this paper sponsored by Committee on Rural Public Transportation.